# URBAN WETLAND EVALUATION

Prepared for
The City of West Monroe Louisiana
By

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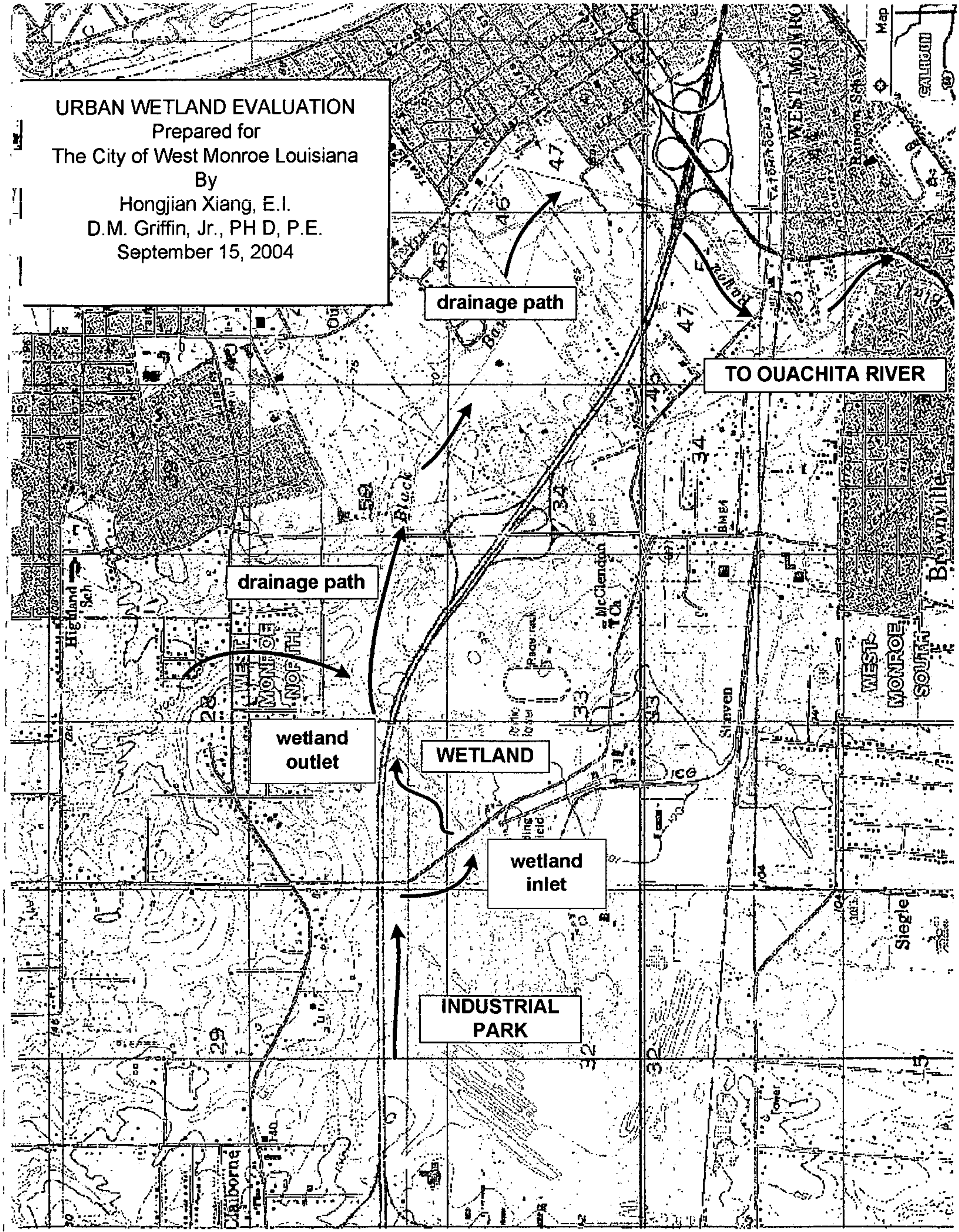


# INTRODUCTION

## Background and description of proposed project

In 1993, Louisiana's Nonpoint Source Management Program targeted seven cities for a series of workshops on urban nonpoint pollution. The purpose of these workshops was to expand the role of LDEQ's urban nonpoint source subcommittee through the implementation of outreach activities which would provide a local forum to allow discussion of problems in areas of the state where urban nonpoint pollution has been identified as a contributing source to water quality impairment. These workshops also provided information on what steps could be taken to alleviate nonpoint contamination problems by implementing best management practices and educational programs. The target audience included city planners, engineers, and community leaders who could facilitate participation in the state's nonpoint source mitigation program. As a result of these workshops the City of West Monroe chose to submit a nonpoint pollution control project for funding through Section 319 of the nonpoint control program, administered by the Environmental Protection Agency. The objectives of Section 319 are to provide accurate documentation of the control of nonpoint pollutant sources, to improve understanding of the nonpoint contamination process, and demonstrate the effectiveness of nonpoint control technologies. Section 319 also provides the framework for funding state and local efforts to control pollutant sources not addressed by the National Pollutant Discharge Elimination System (NPDES). The objectives of the project were to implement best management practices by constructing an urban detention basin, (specifically an extended, wet detention pond) in a portion of the Black Bayou watershed so as to reduce downstream storm water runoff rates, and allow pollutant removal by natural processes, primarily settling. The basin and immediately surrounding area would be developed as a natural area that could also be used for educational and recreational purposes. LDEQ was supportive of this project as a method for implementing best management practices as recommended in EPA's Guidance for Specifying Management Measures for Control of Coastal Nonpoint Sources of Pollution.

As originally conceived, Phase I of the project would examine the effectiveness of the basin in its natural state in reducing downstream flow rates and pollutant concentrations. Phase II would examine the effectiveness of the basin after a dam is constructed at the wetland outlet. Presumably the dam would allow increased detention of storm water, thereby reducing flooding and allowing for increased pollutant removal. A literature review and the results from Phase I of the project were presented in a Master's Thesis published by Cummings (Cummings, 2000). Results from Phase II of the project are presented in this report.

**Watershed and project site description**

Ouachita Parish and the City of West Monroe are located in the Ouachita River basin in north central Louisiana. The Black Bayou drainage area (6430 acres) includes the city of West Monroe. The area drains into Cheniere Brake Lake and the Ouachita River. The project area sub basin is approximately 900 acres (1.4 $mi^2$) in size, is roughly rectangular in shape with the maximum dimension extending east to west. The site abuts the western boundary of the larger Black Bayou watershed as shown in Figure 1. The sub basin is bisected by Interstate Highway 20 (I-20); northern portions of the basin are heavily developed with both commercial and residential areas. Development at the west end of the sub basin is centered on the I-20 interchange at Well Road and a subdivision north of I-20. Development from the east end of the sub basin to the Thomas Road Interchange is primarily commercial. The remainder of the sub basin is forested and contains an abandoned sand and gravel quarry which has become overgrown with time.

The project site is approximately 74 acres in size, owned by the City, and located in the eastern portion of the sub basin, south of I-20. One of the abandoned gravel pits has naturally evolved into a wetland and is used to mitigate storm flows. The wetland itself is approximately 25 acres in size. A dam has been constructed at the outlet of the wetland and the surrounding area has been enhanced to serve as a recreational facility and wildlife habitat. Discharge through the dam drains east to the Ouachita River.

Additional site history and development details can be found in the thesis by Cummings, mentioned earlier.

**Description of sampling sites**

A schematic showing the location of the sampler/flow meters used during phase II of this project is shown in Figure 1. The original intent of this study was to instrument the wetland in such a way as to be able to carry out a mass balance on both flow and contaminants across the wetland for individual rainfall/runoff events. The mass balance concept originates with the fundamental precept that matter can be neither be created nor destroyed. Thus, contaminants entering the basin are either retained in the basin or are discharged at the outlet. By measuring flow and pollutant concentrations entering and leaving the wetland, pollutant loads entering and leaving the wetland can be computed.

In Figure 6 the view is to the northwest. Flow from the area south of I-20 between the wetland outland and Downing Pines Road travels parallel to Constitution Avenue to the outlet in the photo. Some flow from north of the interstate passes beneath I-20 and combines with the flow traveling parallel to I-20; the flow from site 3 discharges just upstream of the flow measuring section at site 2 and just downstream of the wetland outlet.

**Figure 6 - monitoring site 3**

**Figure 7 - monitoring site 4**

Monitoring site 4 is shown in Figure 7. In Phase 1 of this project site 4 was located where flow from the industrial park passed beneath Downing Pines Road. The flow measuring section was originally a corrugated culvert under the roadway. In the interval between phase I and phase II of the project the culvert was replaced with 3 box culverts in parallel. In order to keep from having to instrument all 3 culverts separately (too expensive), it became necessary to move the measuring section approximately 50 yards downstream as shown in Figure 7. The velocity probe and sampling tube were mounted on the bottom of the stream. The shape of the channel was approximated as a trapezoid and input into the flow meter. This site monitors all overland flow and contaminants therein actually entering the wetland. It drains an area, to the west of Downing Pines Road currently being developed as a commercial and industrial park. Some residential area north of I-20 passes beneath I-20 and combines with the flow from the industrial park. Site 4 was the source of problems in obtaining accurate flow measurements and samples during phase I of this project. The area had previously been a sand and gravel quarry and when the accumulated plant growth was cleared, the underlying soil became extremely erodable. During rainfall events, particularly large ones, substantial quantities of sand and gravel were transported downstream. This material covered the velocity and sampling probes, making data collection difficult if not impossible. The gravelly nature of the channel material is visible in the form of a gravel mound in the foreground of Figure 7. A second mound is visible on the channel bottom immediately to the left of the sampler/flow meter. In addition, 2 of the 3 box culverts running beneath Downing Pines Road have substantial accumulations of gravelly sediment that block dry weather flows. This material was not present prior to initiation of the project, rather it was transported from the west side of Downing Pines Road during rainfall events Transport of substantial quantities of this material have continued into Phase II of this project and caused problems. This presented difficulties in sampling and flow measurement that will be discussed later.

# METHODOLOGY

**Events monitored**

The events monitored and reported in this report are listed in Table 1. As shown, 26 events occurred where data was collected, 11 events where data were obtained from all four sampler/flow meters. Wetland efficiencies were computed if data were obtained from sites 2 and 4. Thus, there were 12 events where removal efficiencies could be computed. If data was NOT obtained from sites 2 and 4, pollutant loads were computed from sites where data was collected but wetland efficiencies could not be computed.

**Table 1 monitored events**

| Events | Date | Site1, 2, 3 & 4 | Site1, 2 & 3 | Site1, 2 & 4 | Site2 & 4 | Site1 & 2 | Site2 & 3 | Site1 & 4 | Site2 | Site3 | Site4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 9/18/02 | | | | | | | | | X | |
| 2 | 9/20/02 | | | | | X | | | | | |
| 3 | 9/30/02 | | | | | | | | | X | |
| 4 | 10/4/02 | | | | | X | | | | | |
| 5 | 10/21/02 | | X | | | | | | | | |
| 6 | 11/4/02 | | | | | X | | | | | |
| 7 | 11/11/02 | | | | | | | | X | | |
| 8 | 11/22/02 | | | | | | | | X | | |
| 9 | 12/5/02 | | | | | | X | | | | |
| 10 | 1/27/03 | | | | X | | | | | | |
| 11 | 2/7/03 | | | | X | | | | | | |
| 12 | 2/11/03 | | | X | | | | | | | |
| 13 | 2/17/03 | | | | | | | X | | | |
| 14 | 2/22/03 | X | | | | | | | | | |
| 15 | 3/6/03 | X | | | | | | | | | |
| 16 | 3/20/03 | X | | | | | | | | | |
| 17 | 3/27/03 | | | | | | | | | | |
| 18 | 4/4/03 | | | | | | | | | | X |
| 19 | 4/7/03 | X | | | | | | | | | |
| 20 | 4/25/03 | | | | | | | | | | |
| 21 | 5/4/03 | X | | | | | | | | | |
| 22 | 5/8/03 | X | | | | | | | | | |
| 23 | 5/16/03 | | | X | | | | | | | |
| 24 | 6/18/03 | X | | | | | | | | | |
| 25 | 7/8/03 | X | | | | | | | | | |
| 26 | 7/10/03 | X | | | | | | | | | |
| Total | | 11 | 1 | 2 | 2 | 3 | 1 | 1 | 2 | 2 | 1 |

**Quantifying rainfall events – rainfall hyetographs**

A plot of rainfall vs. time is called a "hyetograph". Hyetographs were produced for all except one of the events described herein. For unknown reasons rainfall data were not logged properly for the event occurring on 1-27-03. As with hydrographs, a single "download" might include a continuous hyetograph for multiple events. It was necessary therefore to determine the rainfall causing a corresponding event hydrograph by examining starting and ending times. This is illustrated in Figure 8 which shows a complete "download". The plot exhibits three separate rainfall events, however the event that actually caused the measured runoff hydrograph occurred between the hours 280 and 300 and is re-plotted to better show the rainfall pattern. The volume of rainfall can be computed by multiplying the point rainfall by the area over which it fell.

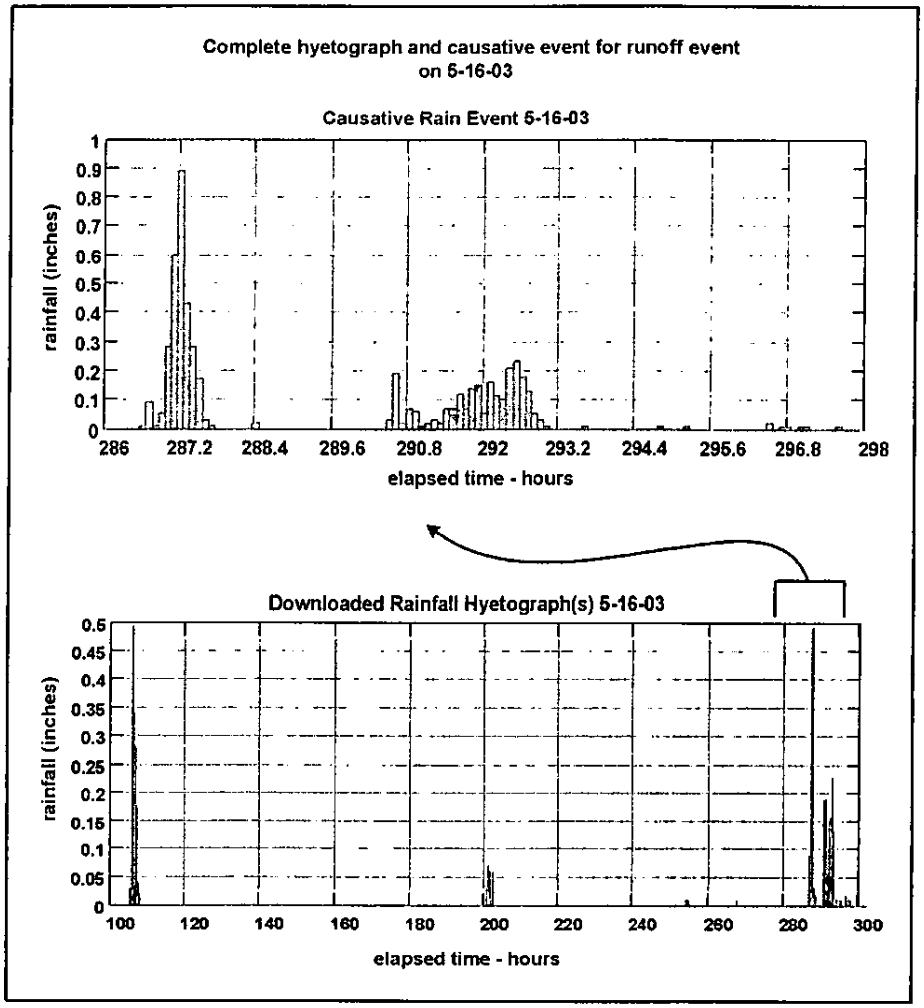
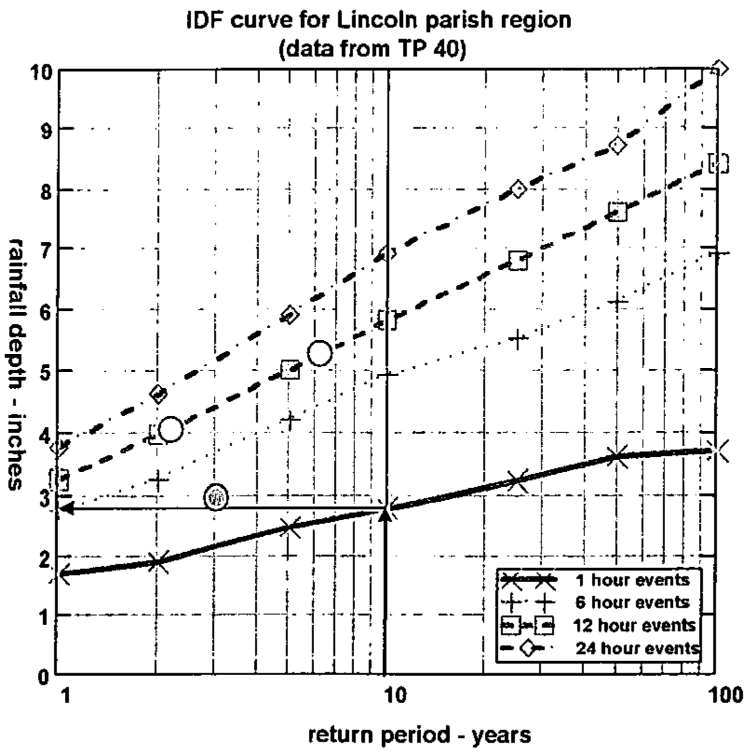



**Figure 8 - Hyetograph analysis for event on 5-16-03**

In order to provide some historical perspective as to the size of the events monitored Figure 9 shows three of the events plotted on what is essentially an intensity-duration-frequency curve (IDF curve) for the Lincoln Parish Region. The events monitored on 5-8, 5-16, and 6-18 had return periods greater




See arrows above:
The 1-hour rainfall amount that can be expected to occur on the average once in every 10 year period is approximately 3". Data extracted from "TP - 40"

○ event on 5-16-03

○ event on 6-18-03

◎ event on 5-8-03

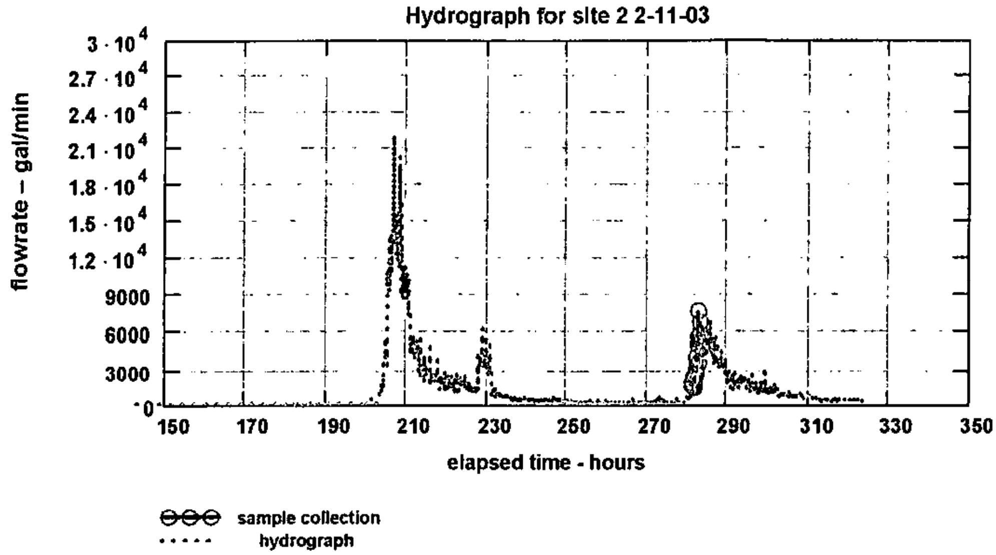
Figure 9 IDF curve Lincoln parish

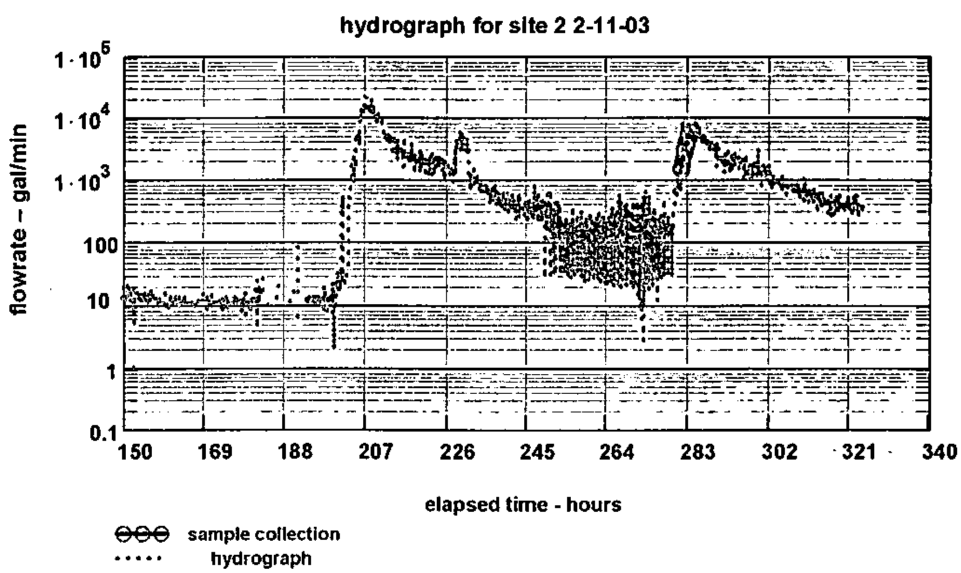
than one year. The remaining events have return periods less than 1 year. Therefore, the performance of the wetland cannot be attributed an abnormal year in terms of the return period of the events measured.

**Quantifying Runoff Flow Rates and Volumes - Event Hydrographs**

A plot of flow rate vs. time at a point is called a "hydrograph". Hydrographs (also referred to here as a "runoff hydrograph") were developed at each of the four monitoring stations for each monitored runoff event. However, only hydrographs from sites 2 and 4 are presented here. An example of a runoff hydrograph is shown in Figure 10, below.

## Site 2
## 2-11-03




Signal starts at 9:18 p.m. on Jan. 28, and ends at 9:24 pm on Feb. 11.

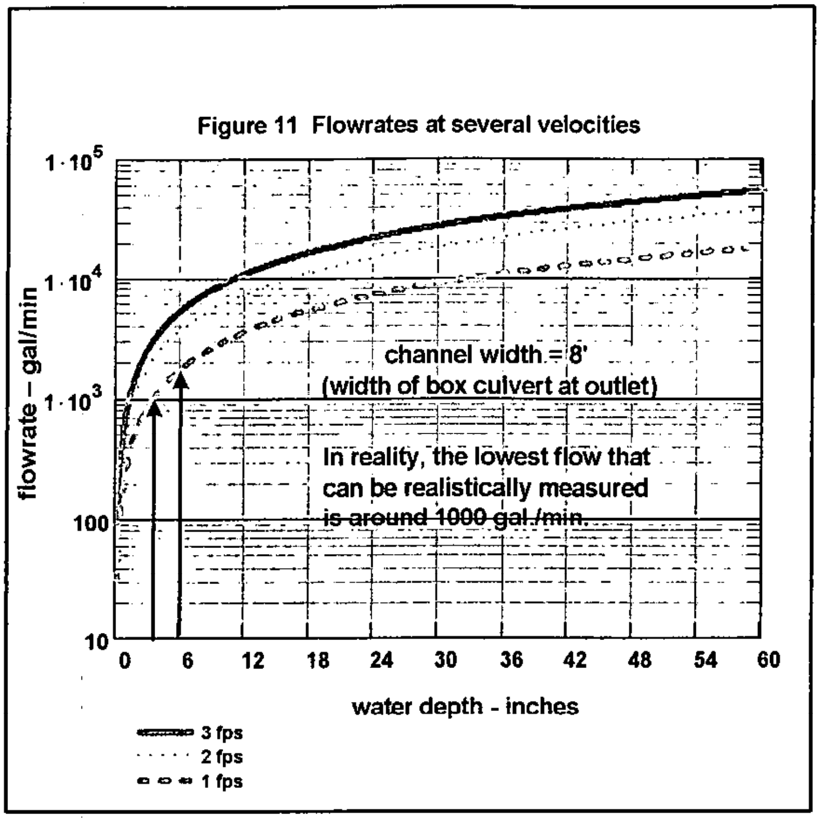
**Figure 10 Runoff hydrograph site 2, event on 2-11-03**

The hydrograph occurred at site 2, the wetland outlet, for an event on February 11, 2003. Data are plotted arithmetically as well as on semi-logarithmic axis. Semi-log plots were used to better show the wide variations in flow, particularly during low flows. Flow rates, routinely varied over 4 orders of magnitude, from 10 gal/min to $10^4$ gal/min during a single event. The rapid variation in flow between hour 245 and hour 280 is characteristic of the measuring probe at shallow depths and lower flow rates. According to American Sigma support personnel:

> "Essentially, the probe has to be completely covered and the velocity a value that will not create turbulence around the probe. While the probe will theoretically work down to about 1 inch of flow, the data is usually noisy. Generally, 1.5 inches of depth (bottom of probe to surface) is needed with velocities up to about 2 fps (depends on channel slope, etc.), and 2 + inches of depth if the velocity is over 2 fps. Also, keep in mind that the velocity signal is projected upstream from the beveled edge of the probe, so you want consistent flow upstream. I've seen upstream turbulence 15 feet away cause errant velocity readings. You also don't want velocities less than 0.5 fps. While the probe can read these with enough suspended solids, the solids are usually settling out too much at below 0.5 fps."

In order to illustrate how flow depths and flow rates were related in this study, a plot of flow rate vs. depth of flow in an 8 ft. wide box culvert is shown in Figure 11. The plot suggests that a practical lower limit for reliable flow measurement is about 1000 gal/min, given the flow sections used in this study. However, because of the high flows normally measured in the events described herein, these smaller flows did not appear to unduly affect mass balance calculations.

Note that the hydrograph shown above has two peaks. Data from the sampler/flow meters were downloaded as soon as possible after rainfall events and, during rainy periods, hydrographs from multiple events were often downloaded. Corresponding inlet and outlet hydrographs as well as rainfall data were matched up based on their time of occurrence. In order to carry out a correct mass balance only corresponding portions of inlet and outlet hydrographs could be compared. This sometimes required determining the volume of runoff corresponding to only a portion of a hydrograph so as to be consistent. The problem is illustrated in Figure 12. The hydrograph at the outlet exhibits two peaks. However, the inlet hydrograph corresponds only to the second peak on the outlet hydrograph. Therefore, the volumes and pollutant loads from the second peak at the outlet were compared to the volume and pollutant loads at the inlet.




For several events the volume leaving the wetland is substantially larger than the volume entering. Based on field observations, the reason for this is believed to be abbreviated flow measurement occurring at site 4, the wetland inlet. As noted earlier this entire area, including that being developed as an industrial park, had previously been a sand and gravel quarry. Some years ago the quarry ceased operation and, in the meantime, the site became overgrown with vegetation. Early in Phase I of the project the vegetative covering on what is now the industrial park area was removed. As a result, the underlying soil, being highly erodable was transported into the wetland during runoff events. Much of this material was too large to be suspended in the flow and was transported as bedload. As the flow velocity dropped during the receding leg of the hydrograph this material ceased movement, covering the velocity probe (observed for several events) and eliminating the velocity signal. Subsequent flow passing the probe was not recorded resulting in the inflow hydrograph being prematurely truncated, reducing the runoff volume measured. Table 2 shows the measured runoff volumes for the events discussed.

**Table 2 - Runoff volumes measured (million gallons)**

| Date | Rainfall (inches) | Site 1 Vol. (MG) | Site 2 Vol. (MG) | Site 3 Vol. (MG) | Site 4 Vol. (MG) | in-out |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | 1.21 | na | 10.7 | 9.49 |
| 2/7/03 | 1.14 | na | .193[1] | na | 1.07[2] | .88 |
| 2/11/03 | 0.64 | .04 | 4.3*/12.7 | na | 19.8 | 15.5 |
| 2/22/03 | 4.38 | .752 | 59.8 | .03 | 59.8 | 0.0 |
| 3/6/03 | 0.65 | .07 | 6.0 | .006 | 12.8 | 6.88 |
| 3/20/03 | 0.39 | .02 | 1.3 | .03 | 7.4 | 6.15 |
| 5/4/03 | 0.46 | .02 | 1.8 | .01 | 5.3 | 3.53 |
| 5/8/03 | 3.15 | .24 | 19.3 | .02 | 11.3[2] | -8.0 |
| 5/16/03 | 5.30 | .64 | 40 | na | 32.6[2] | -7.4 |
| 6/18/03 | 4.14 | .37 | 26.5 | .04 | 24.7[2] | -1.4 |
| 7/8/03 | 0.91 | .08 | .6 | .07 | 0.52[2] | -.08 |
| 7/10/03 | 0.19 | | 4.4 | | 3.25[2] | -1.15 |

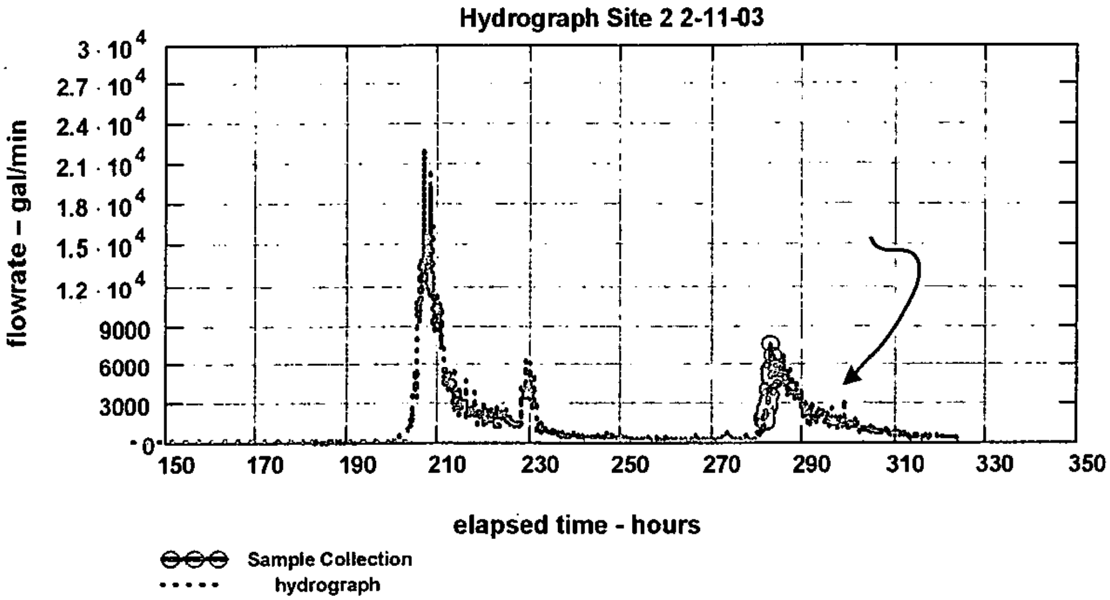
* second flow peak only

[1] possible abnormal hydrograph termination

[2] possible incomplete inflow hydrograph

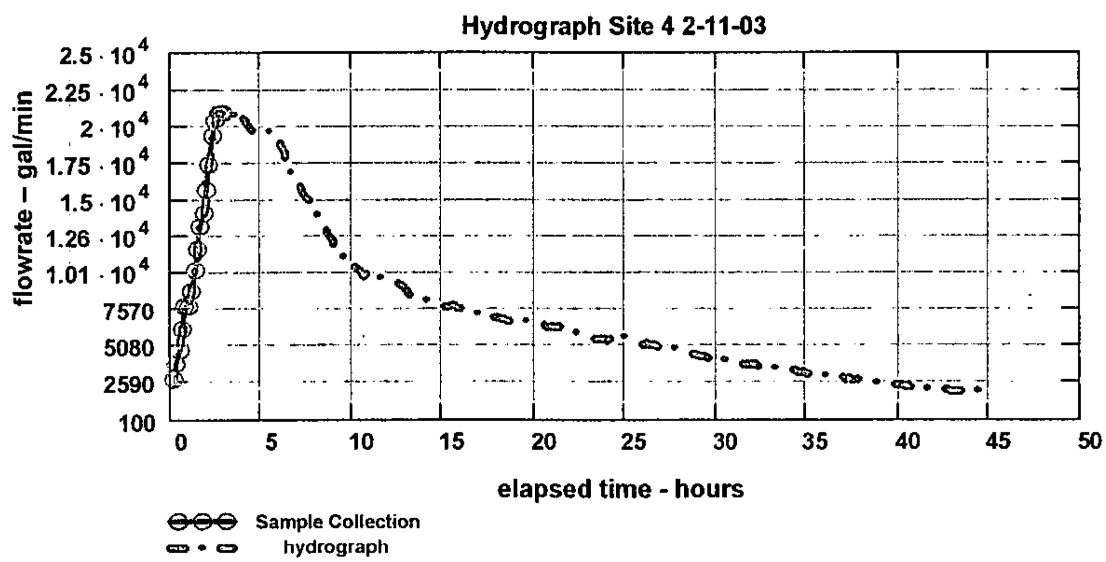
Ostensibly the 3 largest events (5/16/03, 6/18/03 and 7/8/03) as well as the event on 7/10/03 suffered from abbreviated flow measurement. Nevertheless, remaining portions of the hydrographs (rising leg, peak flow rate) at site 4 are considered accurate.

**Sites 2 and 4**
**2-11-03**




**Rain 2.53 inches**

**Site 2 Signal starts at 9:18 p.m. on Jan. 28, and ends at 9:24 pm on Feb. 11, 2003. First Peak 3 am 2-6-03, last peak 6 am 2-9-03. <u>Only last peak corresponds to flow at Site 4.</u>**




**Site 4 Signal starts at 12:30 pm. on 2/9/2003, and ends at 9:00 a.m on 2/11/2003. Peak at 4:30 pm 2-9-03**

**Figure 12 – Runoff hydrographs at sites 2 and 4, event on 2-11-03**

Table 3 below shows the peak flows for the inlet and outlet hydrographs for each event as well as the time between these peaks. Significant attenuation of the flow peak occurs across the wetland as would be expected due to over bank storage. Using the average time between the peaks as a measure of detention time in the wetland, the detention time of water in the wetland during these events is approximately 2.1 hours (.09 days). Because the primary removal mechanism at this site is presumed to be settling it is reasonable to ask if a particle of a given size could be removed during a runoff event. This question is addressed below by computing the terminal settling velocity of a range of particle sizes.

**Table 3 Maximum flows at inlet and outlet**

| Date | Rainfall (inches) | $\Delta t_p$** hrs. | $Q_{max\_in}/Q_{max\_out}$* |
|---|---|---|---|
| 1/27/03 | na | 6 | 22000/2700 |
| 2/7/03 | 1.14 | 1 | 6700/6400 |
| 2/11/03 | 0.64 | 1.5 | 22000/9000 |
| 2/22/03 | 4.38 | 2,2[1] | 70000/90000 |
| 3/6/03 | 0.65 | 3 | 40000/25000 |
| 3/20/03 | 0.39 | 2.5 | 22000/6000 |
| 5/4/03 | 0.46 | 1 | 30000/10000 |
| 5/8/03 | 3.15 | 0.5 | 150000/67500 |
| 5/16/03 | 5.30 | 3.5 | 250000/90000 |
| 6/18/03 | 4.14 | 1.5 | 200000/135000 |
| 7/8/03 | 0.91 | 1.25 | 72000/7000 |
| 7/10/03 | 0.19 | 1.5 | 30000/30000 |
| **average** | | 2.1 | **76225/39883** |

*Ratio of peak flow in to peak flow out (gpm)
**Time between inflow and outflow peaks
[1] peak 1, peak 2
[2] corresponds to entire outflow hydrograph

Figure 13 shows the terminal settling velocities of spherical particles (S.G. = 2.65) computed using Newton's law of settling.

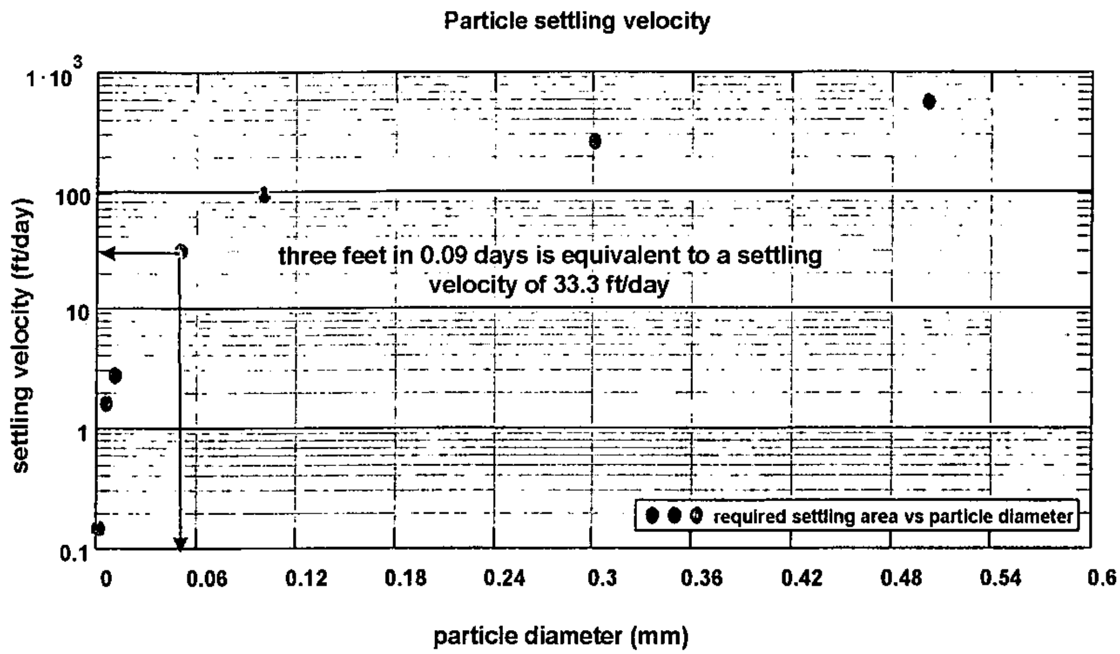



**Figure 13 – Particle settling velocities (computed using Newton's law)**

Assuming an average water depth in the wetland of 3 feet it would take a particle .05 mm in diameter 0.1 days (2.4 hours) to reach the bottom. This suggests that during runoff events many of the smaller sediment particles may pass through the wetland. This hypothesis is supported by the total suspended solids concentrations entering and leaving the wetland. These are listed in Table 4.

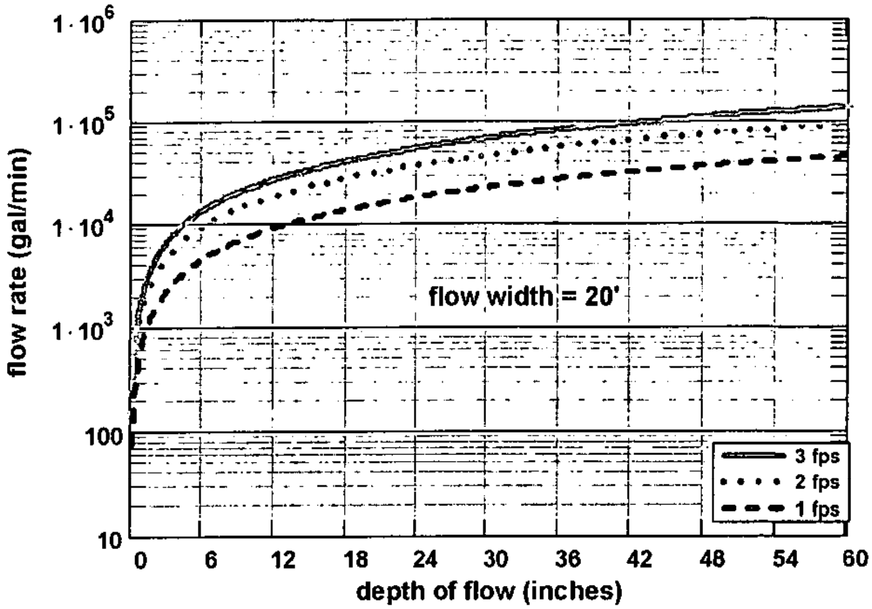
**Table 4 Suspended solids concentrations**

| Date | Rainfall (inches) | TSS site 4 mg/liter | TSS site 2 mg/liter |
|---|---|---|---|
| 1/27/03 | na | 8 | 42 |
| 2/7/03 | 1.14 | 18 | 93 |
| 2/11/03 | 0.64 | 23 | 93 |
| 2/22/03 | 4.38 | 14 | 169 |
| 3/6/03 | 0.65 | 212 | 388 |
| 3/20/03 | 0.39 | 31 | 498 |
| 5/4/03 | 0.46 | 349 | 255 |
| 5/8/03 | 3.15 | 57 | 525 |
| 5/16/03 | 5.30 | 225 | 205 |
| 6/18/03 | 4.14 | 55 | 765 |
| 7/8/03 | 0.91 | 268 | 457 |
| 7/10/03 | 0.19 | 765 | 189 |

As shown, for 9 of the 12 events monitored the TSS concentrations leaving the wetland were greater than those entering. In one instance (5/16/03) the concentrations were about the same and in only 2 instances was the concentration leaving less than that entering.

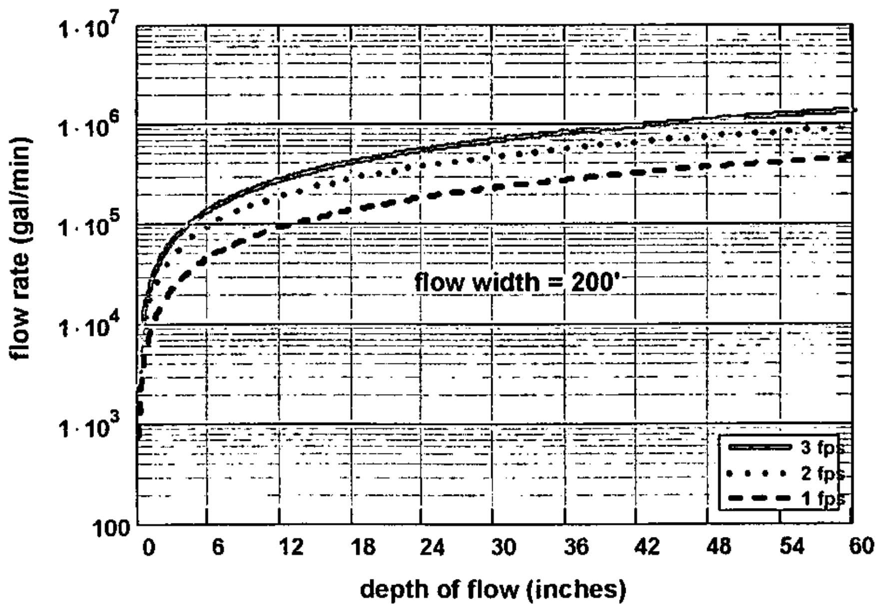
Figure 14 is a plot of velocity vs. flow rate and depth for channel widths of 20' and 200'. The flow velocities plotted are 1, 2 and 3 ft./sec. These were used because values in this range are often cited as scouring velocities in pipes and channels, that is, water flowing at this velocity is capable of entraining particles from the channel bottom. Below each plot are flow rates necessary to provide specified velocities for assumed channel widths. Comparing these values to the peak flows entering the wetland (Table 3) shows that substantial scouring would take place along the entire length of the channel leading into the wetland. Using the water surface elevation of the "one year (24 hour) storm event" shown on the West Monroe Detention Basin Reclamation Area (S.E. Huey 5-4-98) as an estimate of channel width further suggests that much of the upper wetland has flow widths of 200' or less and thus scouring velocities would be prevalent in much of the upper portion of the wetland. For example, in the channel leading to the wetland from Downing Pines Road 11 of the 12 peak flow rates in Table 3 would produce a velocity greater than 3 fps at a depth of 1.0 ft. and the peak flows of the 3 largest events would produce velocities greater than 3 fps at a water depth of 5.0'. The outlet structure from the wetland consists of 2 – 4' diameter pipes with a slope of 0.0089 ft/ft. Assuming uniform flow with no surcharge the flow full velocity through the outlet structure would be approximately 56,000 gal/min. The velocity in each pipe would be 4.76 fps. The significance of this is that the peak outlet flows for the three largest measured events were each greater than 56,000 gal/min. This suggests that velocities greater than 2 ft/sec. near the outlet will limit particle settling in the immediate vicinity of the outlet.

## Figure 14 Velocity vs flowrate and depth




**3 fps flow velocity occurs at 5' depth at 125000 gpm**
**3 fps flow velocity occurs at 1' depth at a flowrate of 26000 gpm**

**1 fps flow velocity occurs at 5' depth at a flowrate of 42000 gpm**
**1 fps flow velocity occurs at a 1' depth at a flowrate of 9100 gpm**




**3 fps flow velocity occurs at 5' depth at 1,100,000 gpm**
**3 fps flow velocity occurs at 1' depth at a flowrate of 267000 gpm**

**1 fps flow velocity occurs at 5' depth at a flowrate of 446,000 gpm**
**1 fps flow velocity occurs at a 1' depth at a flowrate of 95,600 gpm**

# RESULTS

Table 5 shows suspended solids removals across the wetland for the 12 events for which a mass balance could be constructed. The efficiency of the catchment in trapping contaminants was computed as:

$$\text{Removal Efficiency (\%)} = \frac{\text{(contaminants entering} - \text{contaminants leaving)*100}}{\text{contaminants entering}}$$

Seven event efficiencies as well as the overall efficiency of the wetland are negative. A negative efficiency implies that more contaminants left the catchment than entered during the runoff event. It is interesting to note that, in general, the larger the rainfall the more negative the event efficiency. This is consistent with the scouring hypothesis presented earlier. That it, larger events would tend to scour more material than smaller events.

**Table 5 - Total suspended solids loads and removal efficiencies**

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | 426 | na | 717 | 41 |
| 2/7/03 | 1.14 | na | 150.3 | na | 161.8 | 7.0 |
| 2/11/03 | 0.64 | 7.5 | 3381 | na | 3798 | -162 |
| 2/22/03 | 4.38 | 188 | 84320 | 138 | 6982 | -916 |
| 3/6/03 | 0.65 | 388 | 19480 | 47 | 22580 | 16 |
| 3/20/03 | 0.39 | 120 | 5279 | 229 | 1908 | -61 |
| 5/4/03 | 0.46 | 94 | 3934 | 52 | 15280 | 75 |
| 5/8/03 | 3.15 | 2043 | 84320 | 179 | 5370 | -93 |
| 5/16/03 | 5.30 | 1162 | 69620 | na | 61160 | -12 |
| 6/18/03 | 4.14 | 2282 | 169600 | 140 | 11320 | -1376 |
| 7/8/03 | 0.91 | 765 | 2258 | 168 | 1157 | -15 |
| 7/10/03 | 0.19 | 138 | 6932 | 12 | 20800 | 67 |
| **Overall** | | **7188** | **449700** | **965** | **151234** | **-192** |

**Metals**

Metals are important because of their potential toxicity to humans and other higher life forms as well as aquatic organisms. Most metals sorb to sediment particles. In general the smaller sediment fractions have higher metal concentrations because they have more surface area per volume of sediment for sorption to occur. In order to assess the degree of sorption with particle size a sediment sample was taken from the vicinity of the sampling tube at site 4. A sieve analysis was carried out to size fractionate the sediment and each size fraction was analyzed for metals. Sediment metal concentrations are shown in Table 6. The units are (mg metal)/(kg sediment) or ppb. In general, the metal content of the sediment increased as the particle size decreased. The "pan fraction" (grain size < 0.075 mm) exhibited the highest metal concentration. Copper exhibited the highest concentration for all metals except chromium. For chromium, the 170 sieve size fraction produced the highest concentration. Selenium was present in only 2 size fractions of the sediment.

**Table 6 - Metal content vs sediment Size - site 4 (ppb)**

| Sieve number | grain size(mm) | Cr | Pb | Se | Cd | As | Mn | Cu | Hg |
|---|---|---|---|---|---|---|---|---|---|
| 3/8 | 9 | 351.1 | 20.9 | 0 | .96 | 68.8 | 1871.1 | 6.1 | 5.4 |
| 3/4 | 19 | 40.5 | 0 | 0 | 0 | .143 | 61.4 | 4.7 | 4.2 |
| 1/2 | 15 | 16..1 | 0 | 1.43 | 0 | 0 | 378.7 | 2.6 | 2.4 |
| 1 | 26 | 15.9 | 0 | 1.87 | 0 | .27 | 219.1 | 2.5 | 3.1 |
| 4 | 4.75 | 36.2 | 10.3 | 0 | 0 | 3.7 | 1236.4 | 41.3 | 6.7 |
| 10 | 2.00 | 23.9 | 3.7 | 0 | .03 | 1.5 | 635.1 | 60.6 | 46.1 |
| 16 | 1.18 | 62.2 | 7.5 | 0 | .07 | 13.1 | 926.5 | 4.5 | 5.7 |
| 20 | .85 | 21.1 | 8.3 | 0 | .09 | .995 | 716.1 | 66.2 | 50.0 |
| 30 | .60 | 45.0 | 5.5 | 0 | .16 | 7.66 | 703.9 | 4.2 | 4.1 |
| 40 | .43 | 26.2 | 3.9 | 0 | .23 | 6.44 | 781.0 | 2.7 | 3.3 |
| 50 | .30 | 20.9 | 11.65 | 0 | .38 | 4.61 | 1017.2 | 63.8 | 16.9 |
| 60 | .25 | 32.5 | 63.4 | 0 | .5 | 10.4 | 1089.0 | 8.0 | 5.1 |
| 80 | .18 | 42.5 | 36.9 | 0 | .83 | 12.1 | 1500.7 | 39.2 | 12.2 |
| 100 | .15 | 94.3 | 57.9 | 0 | 1.13 | 18.6 | 1849.0 | 25.1 | 17.3 |
| 140 | .11 | 132.1 | 120.6 | 0 | 1.7 | 35.7 | 2259.0 | 58.8 | 16.1 |
| 170 | .09 | 185.6 | 4674.6 | 0 | 15.11 | 88.1 | 2599.7 | 438.5 | 39.1 |
| **pan** | **<.075** | **2161.8** | **2405.5** | **0** | **27.6** | **128.9** | **2685.8** | **4192.0** | **99.9** |

The fact that the majority of the metals sorbed onto sediment particles are on the smallest size fractions is of concern when considered in light of the hydraulics of the wetland, discussed earlier. Because of the apparent scouring that takes place during large runoff events, the short hydraulic detention time in the wetland and the low settling velocities of small particles, not only would the wetland be a net exporter of solids but also of metals.

**Table 7 Arsenic loads and removal efficiencies**

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | .019 | na | .08 | 76.3 |
| 2/7/03 | 1.14 | na | ND | na | ND | ND |
| 2/11/03 | 0.64 | .0012 | .037 | na | ND | source* |
| 2/22/03 | 4.38 | ND | 2.51 | .0024 | ND | source* |
| 3/6/03 | 0.65 | .00006 | .026 | .0027 | .181 | 87 |
| 3/20/03 | 0.39 | ND | .0065 | .0057 | 1.71 | 99 |
| 5/4/03 | 0.46 | .00073 | .075 | .0014 | .304 | 76 |
| 5/8/03 | 3.15 | .038 | 2.82 | .007 | ND | source* |
| 5/16/03 | 5.30 | .0011 | 1.28 | na | .47 | -172 |
| 6/18/03 | 4.14 | ND | ND | ND | ND | ND |
| 7/8/03 | 0.91 | .011 | .019 | .0027 | .016 | 67 |
| 7/10/03 | 0.19 | .002 | .11 | .00018 | 0.2 | 46 |
| **Overall** | | **.054** | **6.89** | **.022** | **2.76** | **-146** |

*wetland a source for this contaminant during this event

This is illustrated for arsenic in Table 7. Based on the 12 events monitored the wetland exported approximately 1.5 times the amount of arsenic entering. Similar results for other metals are provided in Appendix I. During several events the wetland discharged arsenic although none entered.

## Conventional Contaminants

Several conventional contaminants were monitored during this study, these included total Kjeldahl nitrogen (TKN), nitrate ($NO_3^-$), total phosphorous (TP) and chemical oxygen demand (COD). The results for COD are provided in Table 8. The others are listed in Appendix I

**Table 8 Chemical oxygen demand loads and removal efficiencies**

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | 282 | na | 1407 | 80 |
| 2/7/03 | 1.14 | na | 116.9 | na | 617.4 | 81 |
| 2/11/03 | 0.64 | 32.3 | 3069 | na | 11060 | 18.3 |
| 2/22/03 | 4.38 | 479 | 36220 | 14.2 | 28430 | -25 |
| 3/6/03 | 0.65 | 31.4 | 3223 | 84 | 6731 | 54 |
| 3/20/03 | 0.39 | 11.9 | 617 | 21.9 | 2075 | 72 |
| 5/4/03 | 0.46 | 14.7 | 946 | 9.0 | 2273 | 59 |
| 5/8/03 | 3.15 | 140.5 | 10550 | 16.9 | 7716 | -35 |
| 5/16/03 | 5.30 | 233.4 | 1223 | na | 1679 | 41 |
| 6/18/03 | 4.14 | 456 | 12060 | 20.8 | 6958 | -66 |
| 7/8/03 | 0.91 | 25 | 115.6 | 26.6 | 113.5 | 43 |
| 7/10/03 | 0.19 | 29.2 | 783 | 3.3 | 892 | 16 |
| **Overall** | | **1453** | **69205** | **196.7** | **69951** | **3.4** |

No attempt was made to separate soluble from particulate bound COD. While the wetland was not a large overall exporter of COD it did not function to remove substantial amounts of it either. An efficiency of 3.4% can be interpreted to mean that the wetland removed 3.4 lbs of COD for every 100 lbs entering. Three of the 4 largest events had negative efficiencies while smaller events had positive efficiencies, some substantially so. Again, this is consistent with a hypothesis of scouring since smaller events would produce less runoff and lower wetland flow velocities. The overall efficiency may be higher than for TSS and metals because of increased removal of soluble COD by mechanisms other than settling, for example photolysis or microbial degradation.

Overall removal efficiencies for TKN, nitrate and TP (listed in Appendix I) were -2.4%, -133%, and -105% respectively. The large negative removal for nitrate is reasonable because substantial nitrate is most likely created as a result of biological nitrification (ammonia being converted to nitrate) occurring in the wetland. This is not a bad thing since ammonia is highly toxic to higher life forms while nitrate is not. The large negative removal for phosphorus is also reasonable because phosphorous readily sorbs to sediment particles.

# SUMMARY AND CONCLUSIONS

Overall, the removal efficiency of most contaminants ranged from highly negative to slightly positive. A negative efficiency implies that the wetland discharged more contaminants than entered for the period/events studied. Forty percent of the mass of copper entering the wetland in runoff was removed while the mass of suspended solids leaving the wetland was nearly twice that entering (-192%). On an event basis, smaller rainfall events tended to have higher contaminant removals than larger events. Removal efficiencies for the 3 largest events were consistently highly negative while removals for the smaller events 1/27/03 and 2/7/03 were always highly positive. The flow weighted, average, suspended solids concentration in the outflow hydrograph was nearly always higher than the inflow concentration.

The most likely reason for this, in the writer's opinion, is scouring of material from the wetland during larger rainfall events. Event hydrograph flow rates routinely varied by 3-4 orders of magnitude (10 gal/min to $10^4$ gal/min) within relatively short periods of time. Sophisticated modeling of the wetland to determine the velocity field during rainfall events was not possible, however, relatively simple "back of the envelope" calculations (as well as on-site observations) suggest that flow velocities in the entrance channel and in the upper portion of the wetland routinely exceeded scour velocities (2-3 fps). In addition, based on simplified, uniform flow calculations at the outlet conduits, the velocity field in the region of the outlet structure was also high. Terminal velocity calculations based on Newton's Law of settling indicated that a 0.5 mm particle (SG 2.65) would take between .09 and .1 days (2.2 to 2.4 hours) to settle a distance of 3 feet. If the particle were organic in nature with a specific gravity closer to 1.0 this time would increase dramatically. An examination of the times between the peak of the inlet and outlet hydrographs for the events monitored indicated an average detention in the wetland during rainfall events of 2.1 hours. Thus, it appears possible that particles could travel through the wetland to the outlet in less time than it would take them to settle out. Smaller events exhibited higher removal efficiencies presumably because flow velocities were lower reducing scour and allowing settling to occur more readily. These results suggest that while using a wetland such as was done here as a means of removing contaminants from urban runoff is a good idea the process is not as simple as one might think. The wetland and associated outlet must be sized (designed?) to accommodate the flow rates expected while keeping flow through velocities low enough to allow settling and contaminant removal to occur, otherwise the problem of contaminant export may actually be exacerbated.

# APPENDIX 1

# POLLUTANT LOADS AND REMOVAL EFFICIENCIES

**Table A1 Oil and grease loads and removal efficiencies**

| Date | Rainfall (inches) | Site 1 lbs/in | Site 2 lbs/in | Site 3 lbs/in | Site 4 lbs/in | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | na | na | na | NA |
| 2/7/03 | 1.14 | na | na | na | na | NA |
| 2/11/03 | 0.64 | na | na | na | na | NA |
| 2/22/03 | 4.38 | 17.6 | 1597 | .6 | 1147 | -37 |
| 3/6/03 | 0.65 | 1.14 | 141 | .17 | 288 | 54 |
| 3/20/03 | 0.39 | .4 | 0 | .5 | 0 | NA |
| 5/4/03 | 0.46 | 0 | 0 | .21 | 92 | 100 |
| 5/8/03 | 3.15 | 0 | 0 | .47 | 0 | NA |
| 5/16/03 | 5.30 | 0 | 0 | na | 353 | 100 |
| 6/18/03 | 4.14 | 0 | 0 | 0 | 0 | NA |
| 7/8/03 | 0.91 | 0 | 0 | 1.6 | 0 | NA |
| 7/10/03 | 0.19 | 1 | 0 | .12 | 0 | NA |
| **Overall** | | **19.1** | **1738** | **3.67** | **1880** | **8.7** |

**Table A2 nitrate loads and removal efficiencies**

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | 3.85 | na | 34.1 | 88.7 |
| 2/7/03 | 1.14 | na | .61 | na | 2.96 | 79.3 |
| 2/11/03 | 0.64 | .164 | 14.5 | na | 64.4 | 77.7 |
| 2/22/03 | 4.38 | 2.3 | 164.6 | .073 | 114.7 | -41 |
| 3/6/03 | 0.65 | .64 | 36.1 | .084 | 29.8 | -18.7 |
| 3/20/03 | 0.39 | .079 | 4.35 | .065 | 23.4 | 82 |
| 5/4/03 | 0.46 | .302 | 32.5 | .181 | 57.4 | 44 |
| 5/8/03 | 3.15 | 2.88 | 313.2 | .35 | 141.6 | -119 |
| 5/16/03 | 5.30 | 7.12 | 624.9 | na | 312.7 | -97.5 |
| 6/18/03 | 4.14 | 3.02 | 237.3 | .321 | 166.7 | -40 |
| 7/8/03 | 0.91 | .646 | 6.3 | .786 | 6.13 | 20 |
| 7/10/03 | 0.19 | .718 | 66.9 | .07 | 81.8 | 19.1 |
| **Overall** | | **17.9** | **1504.8** | **1.86** | **1035.69** | **-133** |

**Table A3 TKN loads and removal efficiencies**

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | 157.2 | na | 1264 | 87.5 |
| 2/7/03 | 1.14 | na | 7.6 | na | 53.9 | 86 |
| 2/11/03 | 0.64 | 1.9 | 294 | na | 1668 | 82.4 |
| 2/22/03 | 4.38 | 46.4 | 4361 | 2.7 | 3017 | -43 |
| 3/6/03 | 0.65 | 3.35 | 538.4 | .52 | 500.5 | -6.7 |
| 3/20/03 | 0.39 | 1.18 | 73.1 | 2.0 | 381.6 | 81.6 |
| 5/4/03 | 0.46 | 1.1 | 114.2 | 0.9 | 262.7 | 57.2 |
| 5/8/03 | 3.15 | 15.0 | 1381 | 1.99 | 951.5 | -43.3 |
| 5/16/03 | 5.30 | 39.6 | 2038 | na | 1278 | -56.4 |
| 6/18/03 | 4.14 | 23.1 | 1330 | 2.5 | 967.5 | -34.8 |
| 7/8/03 | 0.91 | 3.8 | 30.1 | 4.3 | 23.3 | 5.5 |
| 7/10/03 | 0.19 | 2.0 | 188.4 | .25 | 165.8 | -12.3 |
| **Overall** | | **137.4** | **10512** | **15.2** | **10334** | **-2.4** |

**Table A4 TP Loads and Removal Efficiencies**

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | 2.84 | na | 15.2 | 81.2 |
| 2/7/03 | 1.14 | na | .43 | na | .81 | .47 |
| 2/11/03 | 0.64 | .24 | 9.4 | na | 26.4 | 65 |
| 2/22/03 | 4.38 | 1.63 | 164.6 | .153 | 69.8 | -133 |
| 3/6/03 | 0.65 | .512 | 10.04 | .015 | 21.3 | 55 |
| 3/20/03 | 0.39 | .017 | 1.8 | .038 | 1.2 | -31.4 |
| 5/4/03 | 0.46 | .162 | 7.6 | .076 | 26.7 | 72.4 |
| 5/8/03 | 3.15 | 1.5 | 81.9 | .154 | 69.7 | -15 |
| 5/16/03 | 5.30 | 3.75 | 152.8 | na | 176.7 | 15.6 |
| 6/18/03 | 4.14 | 7.7 | 494.6 | .498 | 65.9 | -532 |
| 7/8/03 | 0.91 | .27 | 2.1 | .22 | 1.38 | -16.6 |
| 7/10/03 | 0.19 | .37 | 10.7 | .011 | 14.4 | 28.3 |
| **Overall** | | **16.1** | **1023** | **1.1** | **490** | **-105** |

**Table A5 Cadmium loads and removal efficiencies**

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | .0008 | na | 0 | source* |
| 2/7/03 | 1.14 | na | 0 | na | .005 | 100 |
| 2/11/03 | 0.64 | .00005 | .0032 | na | 0 | source* |
| 2/22/03 | 4.38 | 0 | 0 | 0 | 0 | na |
| 3/6/03 | 0.65 | 0 | 0 | 0 | 0 | na |
| 3/20/03 | 0.39 | .00025 | .014 | .0003 | .014 | 2.3 |
| 5/4/03 | 0.46 | .000014 | .00092 | .000008 | .0022 | 59 |
| 5/8/03 | 3.15 | .00012 | .014 | .000031 | .015 | 7.6 |
| 5/16/03 | 5.30 | .00037 | .048 | na | .022 | -116 |
| 6/18/03 | 4.14 | 0 | 0 | 0 | 0 | na |
| 7/8/03 | 0.91 | .00015 | .0022 | .00005 | .0002 | -100 |
| 7/10/03 | 0.19 | .00005 | .001 | .000002 | .0054 | .43 |
| **Overall** | | **.001** | **.084** | **.00039** | **.059** | **-40** |

*wetland a source for this contaminant during this event

**Table A6 Chromium loads and removal efficiencies**

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | .051 | na | .247 | 79.3 |
| 2/7/03 | 1.14 | na | .0075 | na | .017 | 56 |
| 2/11/03 | 0.64 | .00097 | .16 | na | .424 | 62 |
| 2/22/03 | 4.38 | .021 | 2.62 | .0037 | 1.65 | -57 |
| 3/6/03 | 0.65 | .0015 | .218 | .0014 | .517 | 58.4 |
| 3/20/03 | 0.39 | .0018 | .139 | .0065 | 0 | source* |
| 5/4/03 | 0.46 | .0023 | .201 | .0020 | .54 | 76 |
| 5/8/03 | 3.15 | .027 | 1.84 | .0047 | .411 | -339 |
| 5/16/03 | 5.30 | .034 | 2.72 | Na | 2.94 | 8.6 |
| 6/18/03 | 4.14 | .206 | 5.19 | .0064 | 2.78 | -78 |
| 7/8/03 | 0.91 | .025 | .078 | .0086 | .039 | -104 |
| 7/10/03 | 0.19 | .0079 | .309 | .00055 | .755 | 60 |
| **Overall** | | **.33** | **13.5** | **.033** | **10.32** | **-27.3** |

*wetland a source for this contaminant during this event

Table A7 Copper loads and removal efficiencies

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | .096 | na | .476 | 79.8 |
| 2/7/03 | 1.14 | na | .03 | na | .052 | 42 |
| 2/11/03 | 0.64 | .0027 | .404 | na | 1.13 | 64 |
| 2/22/03 | 4.38 | .058 | 6.7 | .0048 | 18.3 | 63.7 |
| 3/6/03 | 0.65 | .005 | .266 | .00081 | .79 | 67 |
| 3/20/03 | 0.39 | .0021 | .161 | .0087 | .813 | 81.5 |
| 5/4/03 | 0.46 | .0054 | .425 | .0022 | .952 | 56 |
| 5/8/03 | 3.15 | .044 | 3.2 | .0029 | 1.85 | -70 |
| 5/16/03 | 5.30 | .084 | 5.4 | na | 4.04 | .299 |
| 6/18/03 | 4.14 | .067 | 5.6 | .0058 | .299 | -1748 |
| 7/8/03 | 0.91 | .014 | .054 | .0071 | .047 | 30 |
| 7/10/03 | 0.19 | .0079 | .331 | .00057 | .587 | 45 |
| **Overall** | | **.28** | **17.6** | **.032** | **29.3** | **41** |

Table A8 Mercury loads and removal efficiencies

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | Na | .0098 | Na | .19 | 95 |
| 2/7/03 | 1.14 | Na | .0012 | Na | .0099 | 88 |
| 2/11/03 | 0.64 | .00032 | .053 | Na | .205 | 74 |
| 2/22/03 | 4.38 | .0019 | .274 | .00012 | .608 | 55 |
| 3/6/03 | 0.65 | .00034 | .055 | .000026 | .071 | 23 |
| 3/20/03 | 0.39 | .00015 | .011 | .000056 | .055 | 80 |
| 5/4/03 | 0.46 | .00019 | .015 | .000087 | .043 | 65 |
| 5/8/03 | 3.15 | .0020 | .161 | .00017 | .118 | -34 |
| 5/16/03 | 5.30 | .0030 | .088 | Na | .136 | 37.5 |
| 6/18/03 | 4.14 | .00046 | .093 | .000053 | .056 | -65 |
| 7/8/03 | 0.91 | .0025 | .012 | .00094 | .0051 | -68 |
| 7/10/03 | 0.19 | .0008 | .033 | .000027 | .022 | -46 |
| **Overall** | | **.012** | **.791** | **.0015** | **1.52** | **48.8** |

Table A9 Manganese loads and removal efficiencies

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | 2.67 | na | 128.7 | 98 |
| 2/7/03 | 1.14 | na | .522 | na | 1.45 | 64 |
| 2/11/03 | 0.64 | .0096 | 6.3 | na | 22.9 | 72.5 |
| 2/22/03 | 4.38 | .234 | 44.8 | .052 | 174.6 | 75 |
| 3/6/03 | 0.65 | .105 | 12.3 | .016 | 18.1 | 33 |
| 3/20/03 | 0.39 | .05 | 6.4 | .18 | 7.1 | 13 |
| 5/4/03 | 0.46 | .036 | 4.49 | .013 | 16.5 | 73 |
| 5/8/03 | 3.15 | .266 | 44.5 | .037 | 10.9 | -305 |
| 5/16/03 | 5.30 | .74 | 39.4 | .054 | 42.9 | 11.7 |
| 6/18/03 | 4.14 | 1.25 | 114.2 | .054 | 23.7 | -376 |
| 7/8/03 | 0.91 | .715 | 3.6 | .104 | 2.6 | 7.0 |
| 7/10/03 | 0.19 | .144 | 30.3 | .011 | 47.2 | 36.1 |
| **Overall** | | **3.54** | **309.5** | **.62** | **496.7** | **38.5** |

Table A10 Lead loads and removal efficiencies

| Date | Rainfall (inches) | Site 1 lbs | Site 2 lbs | Site 3 lbs | Site 4 lbs | Efficiency % |
|---|---|---|---|---|---|---|
| 1/27/03 | na | na | .051 | na | .103 | 50.4 |
| 2/7/03 | 1.14 | na | .0026 | na | .065 | 96 |
| 2/11/03 | 0.64 | .0014 | .21 | na | .849 | 75 |
| 2/22/03 | 4.38 | .024 | 2.27 | .001 | 1.92 | -16.9 |
| 3/6/03 | 0.65 | .007 | .23 | .00061 | .181 | -23 |
| 3/20/03 | 0.39 | .022 | 1.4 | .013 | 3.5 | 61 |
| 5/4/03 | 0.46 | .0007 | .062 | .00056 | .138 | 56 |
| 5/8/03 | 3.15 | .014 | .723 | .0013 | .12 | -489 |
| 5/16/03 | 5.30 | .01 | .873 | na | .794 | -8.6 |
| 6/18/03 | 4.14 | .11 | 5.93 | .0049 | 1.05 | -453 |
| 7/8/03 | 0.91 | .147 | .158 | .0053 | .037 | 84 |
| 7/10/03 | 0.19 | .0057 | .175 | .00035 | .21 | 19.5 |
| **Overall** | | **.34** | **12.08** | **.027** | **8.97** | **-30.5** |

**APPENDIX II**

**RUNOFF HYDROGRAPHS**

**AND**

**RAINFALL HYETOGRAPHS**

## REFERENCES


RAINFALL FREQUENCY ATLAS OF THE UNITED STATES for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years, TECHNICAL PAPER 40, Department of Commerce, May 1961, Washington, D.C.

Cummings, Karen, The Effects of a Stormwater Detention Basin on Pollutant Loads, A Thesis Presented in Partial Fulfillment of the Requirements for Master of Science, College of Applied and Natural Science, Louisiana Tech University, November 2000

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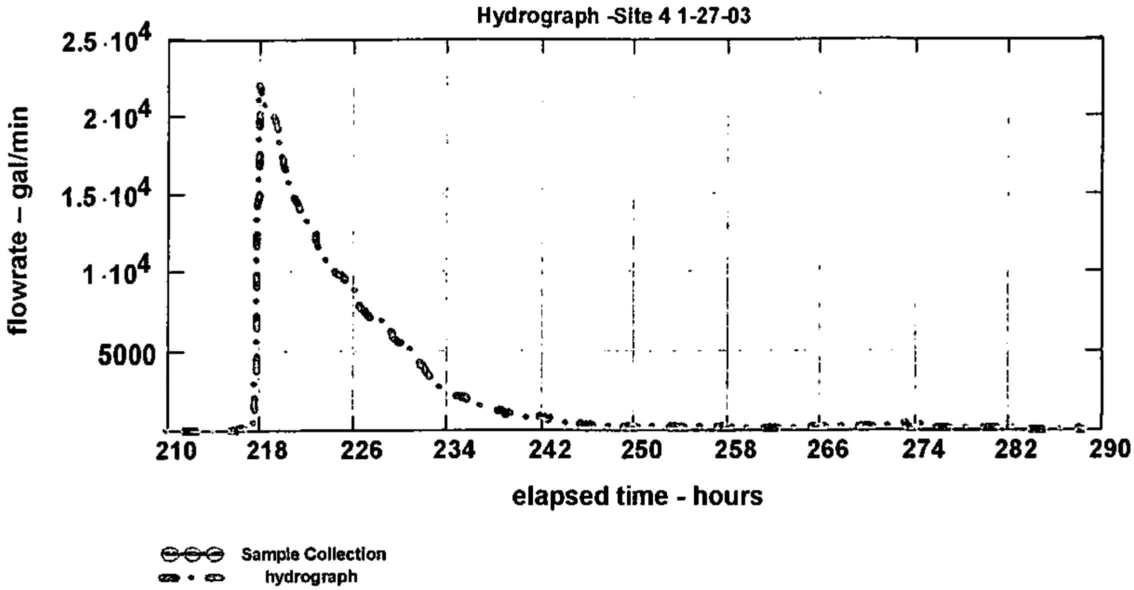
# Appendix

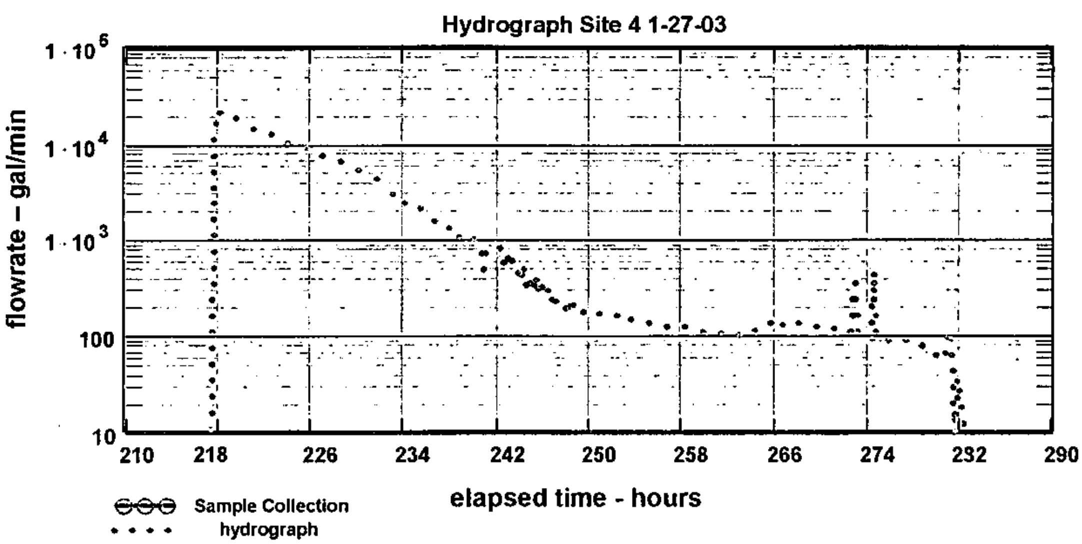
## Runoff Hydrographs at Sites 2 (outlet) and 4 (inlet)

## Causative rainfall Hyetograph for each Event

# Figure A-II-1

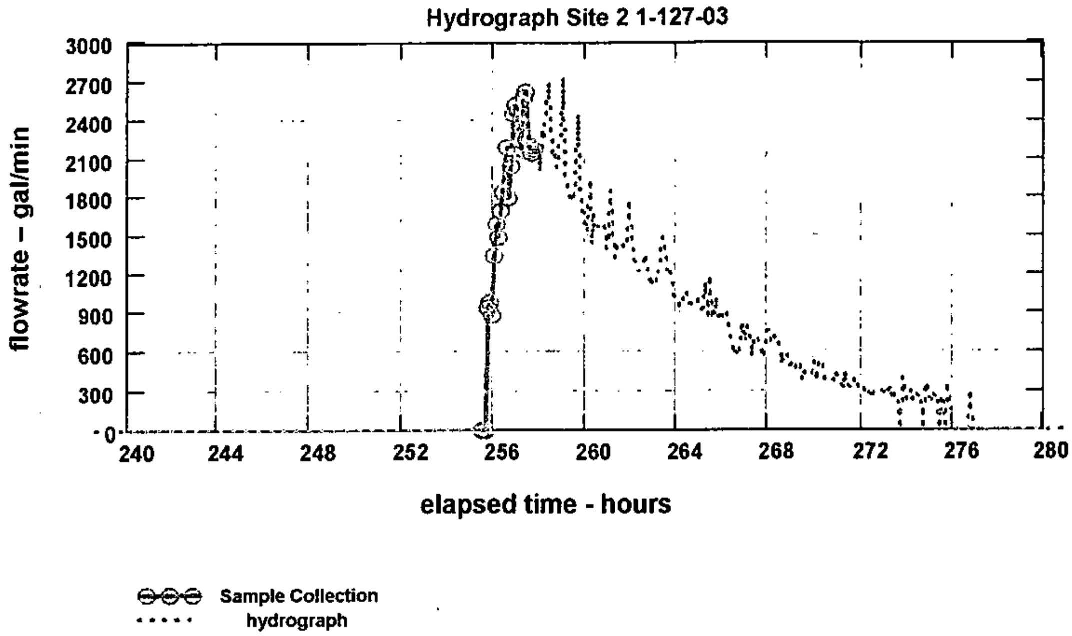
## Site 4
## 1-27-03



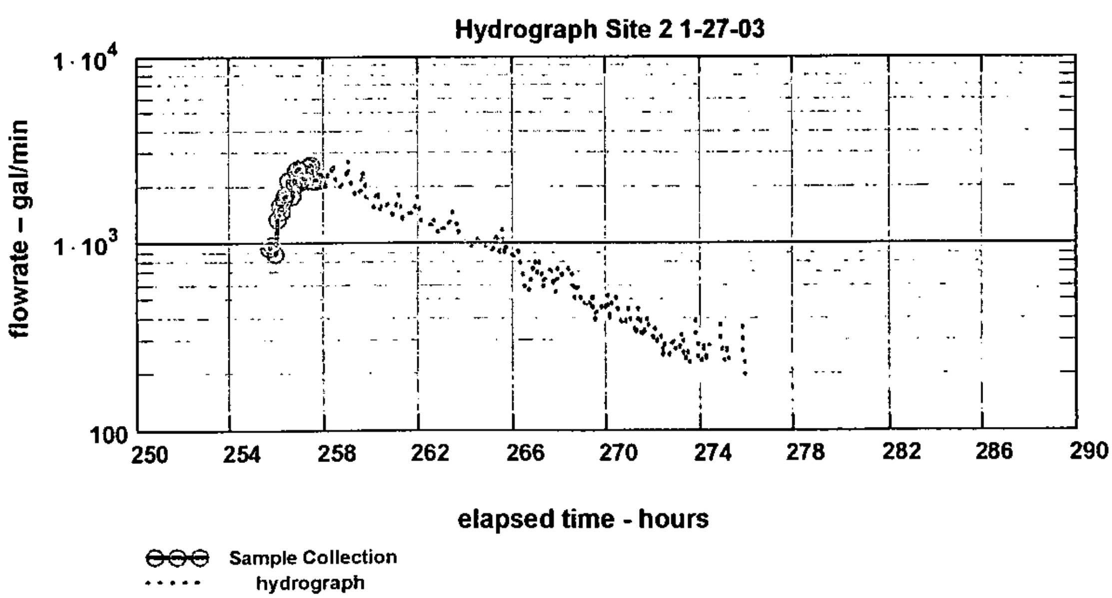




Signal starts at 9:50 a.m. on 1/15/2003, and ends at 10:20 a.m on 1/27/2003.

## Figure A-II -1
## Site 2
## 1-27-03

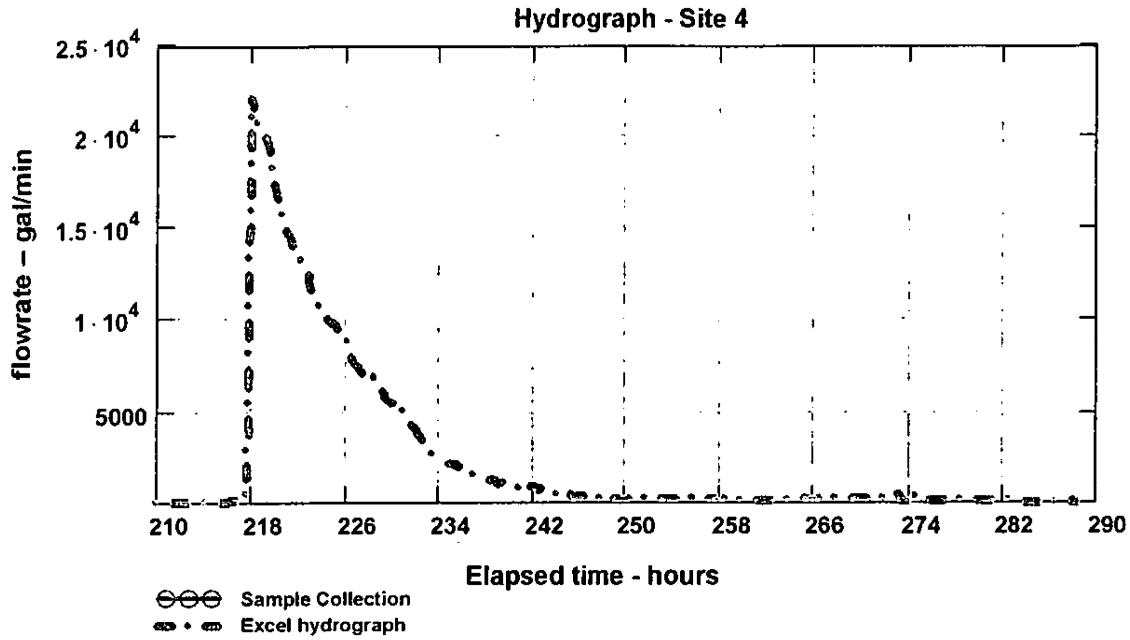



Signal starts at 9:00 p.m. on Jan. 13, and ends at 9:06 a.m on Jan.27, flow was detected every 6 minutes. Total 3242 row of flow for hydrograph.

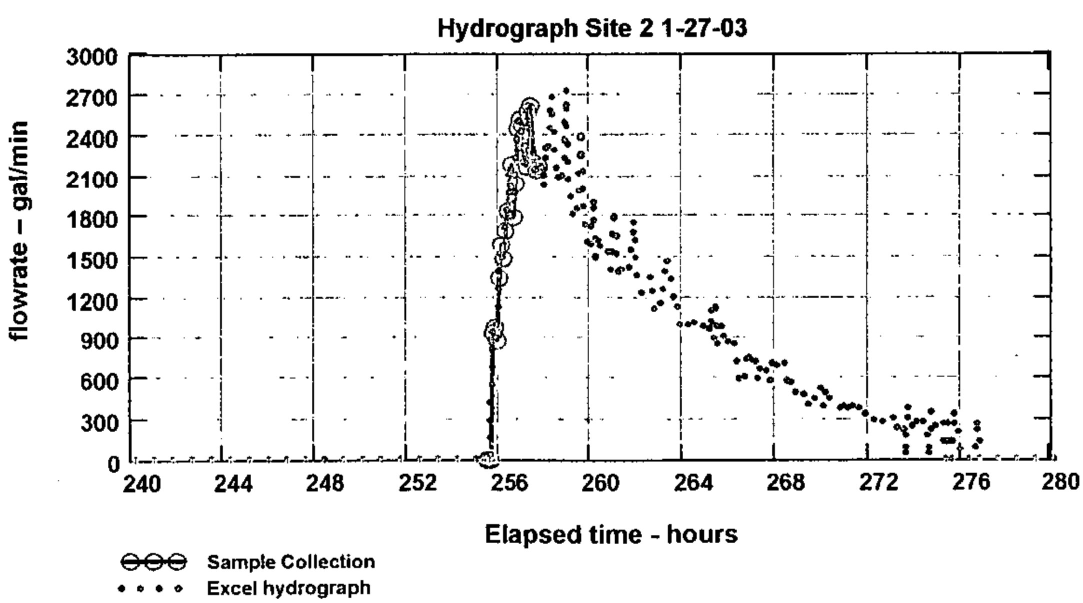


## Figure A-II-1

**Sites 2 and 4**
**1-27-03**

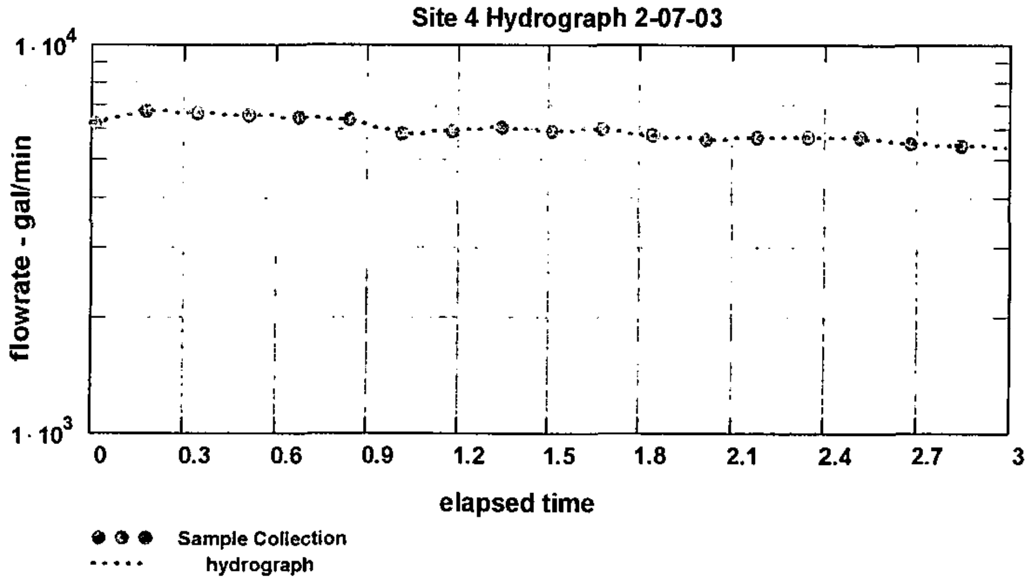


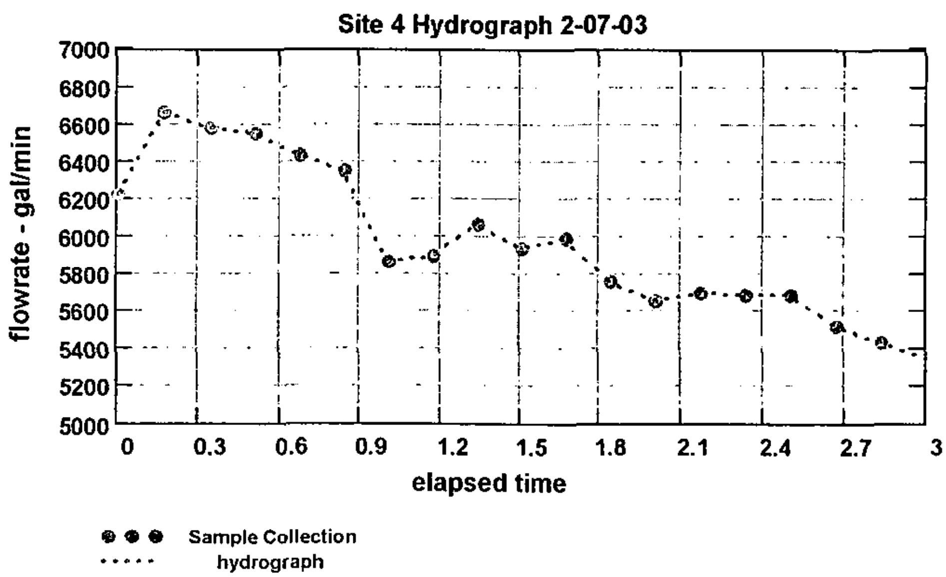

**Site 4 – Signal from 9:50 am 1/15/03 to 10:20 am 1/27/03**
**Peak flow at 10 am 24th**




**Site 2 – Signal from 9 pm 1/13/03 to 9:06 am 1/27/03**
**Peak flow at 4 pm 24th**

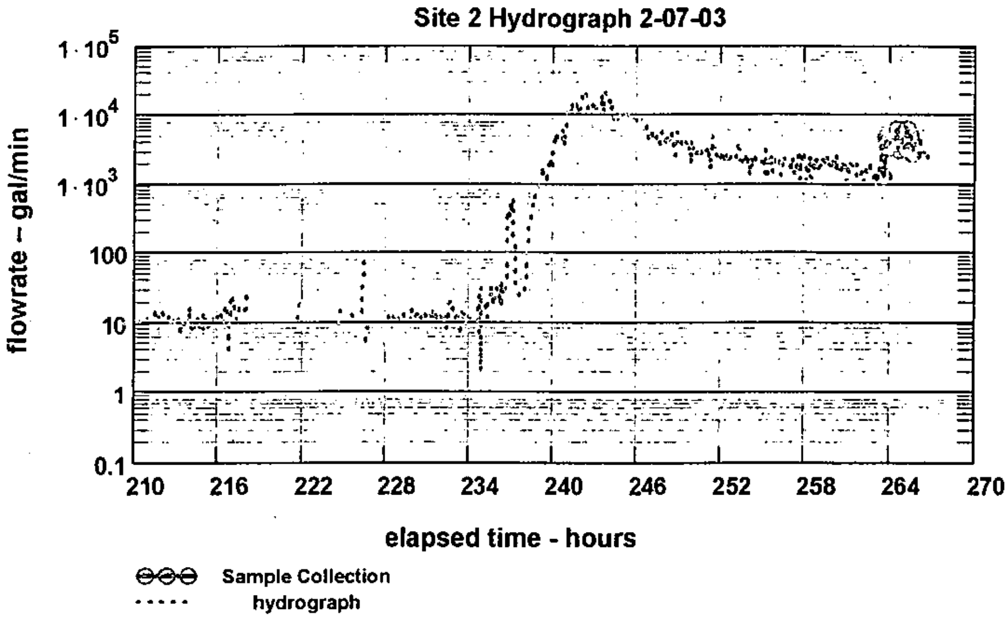
# Figure A-II-2
## Event 2-7-03
## Site 4

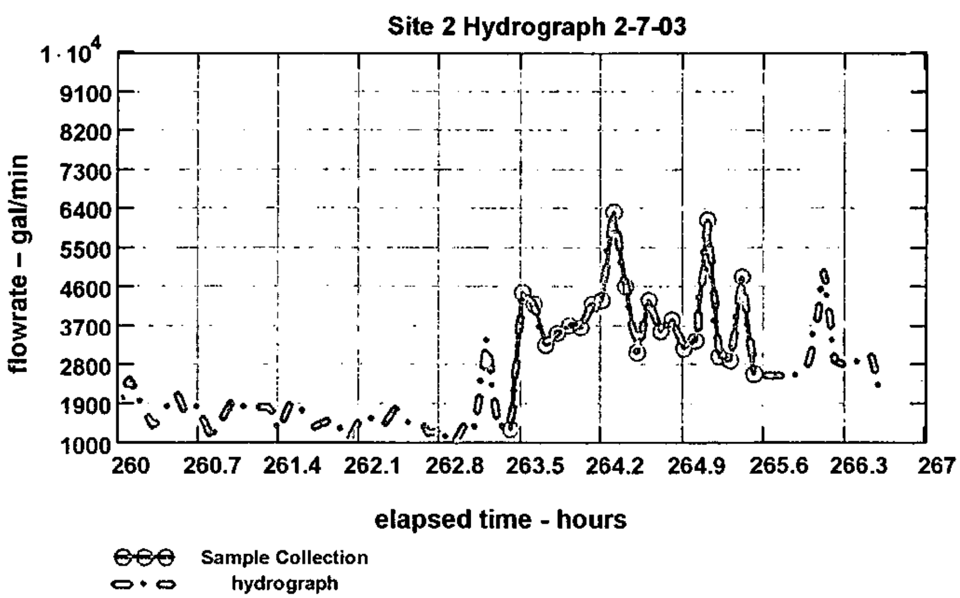


# Figure A-II-2

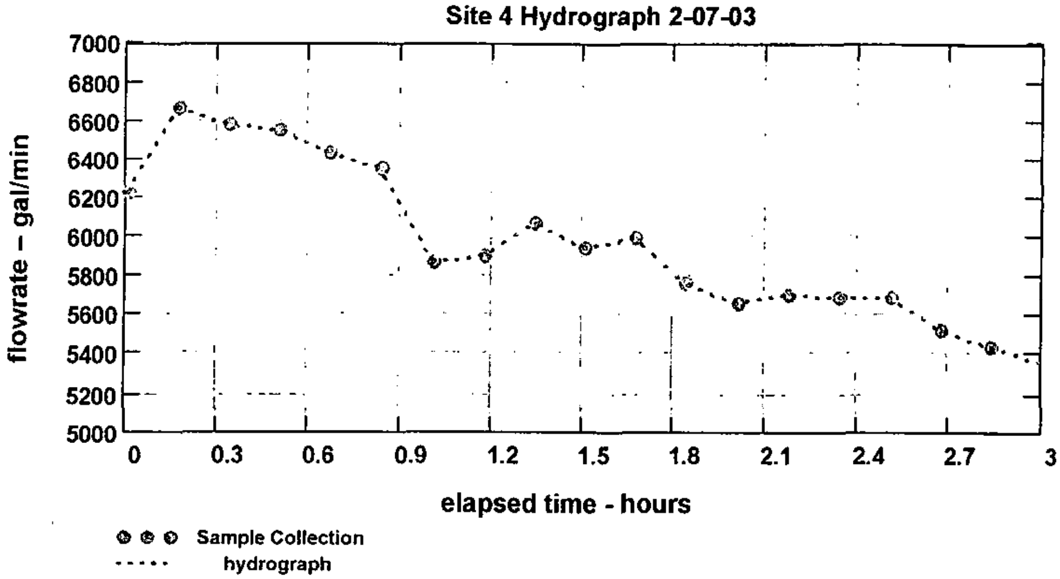
## Event 2-7-03
## Site 2



# Figure A-II-2

## Sites 2 and 4
## 02- 07- 03



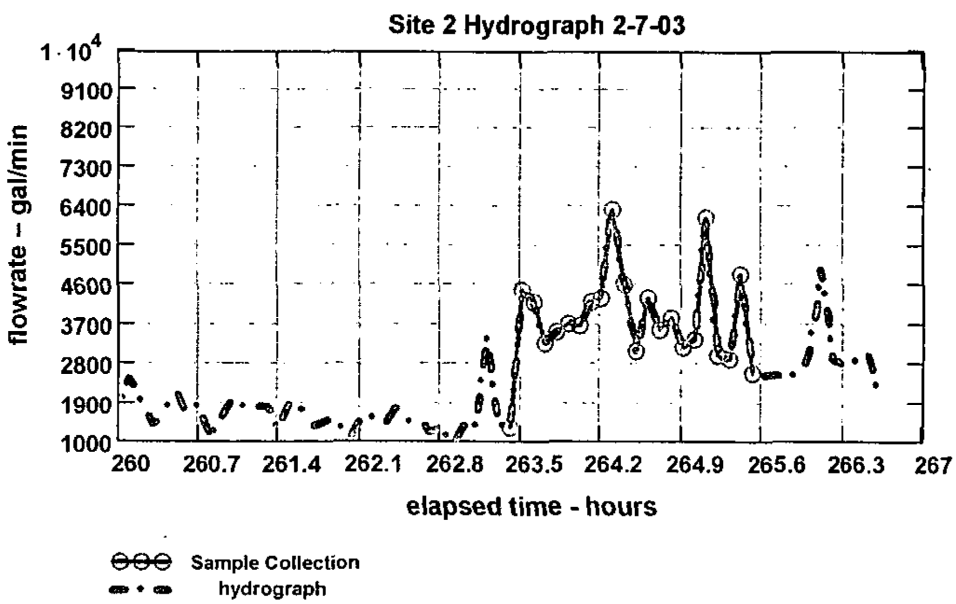

**Site 4 Signal starts at 9:30 a.m. on 2/7/2003, and ends at 12:30 p.m on 2/7/2003, peak at 9:45 am 2/7/03. <u>Inflow hydrograph appears to exhibit abnormal start.</u>**

[illegible]

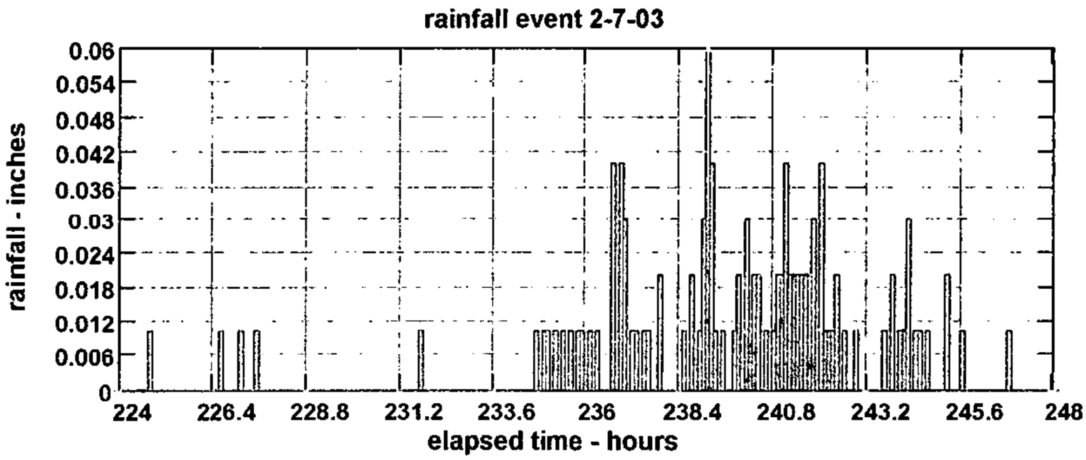
**0.45 in between Jan 29 3:36 am and Jan 29 11:54 am**

**0.22 in between Feb 3, 9:12 am and Feb 3 8:24 pm**

**Site 2 Signal starts at 9:48 a.m. on Jan. 27, and ends at 12:24 pm on Feb. 7.
Peak at 10:45 pm 2-7-03**

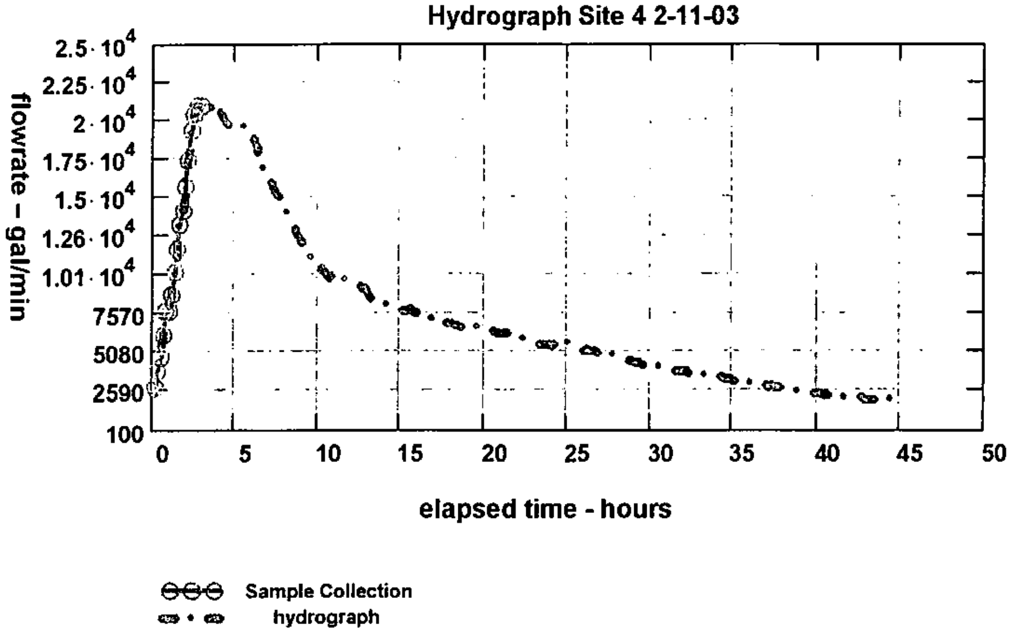


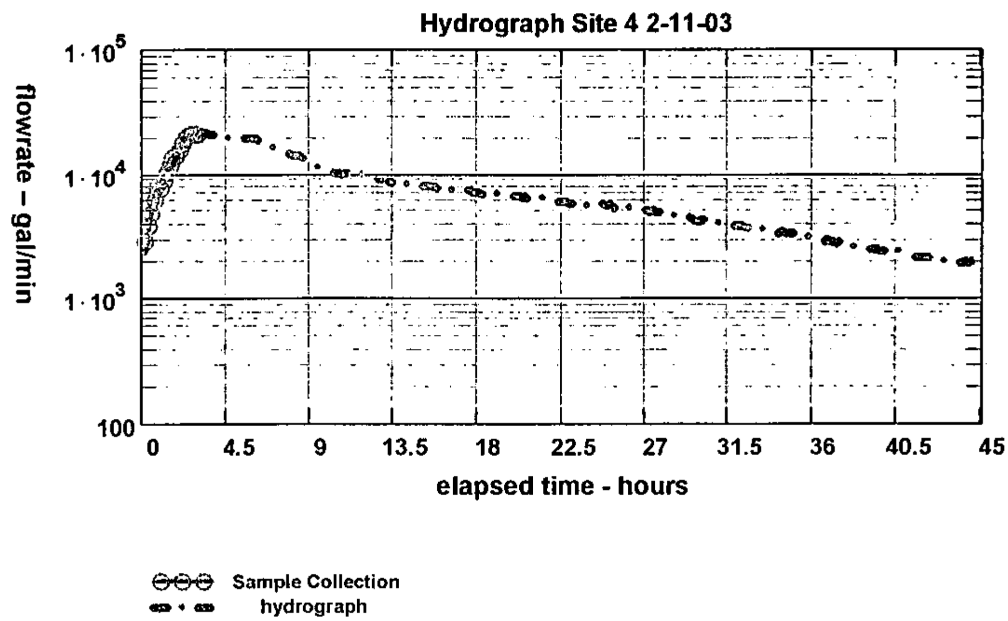
## Figure A-II-2




**1.14 in between Feb 5, 6:24 pm and Feb 6, 4:54 pm**
**(11 hrs)**

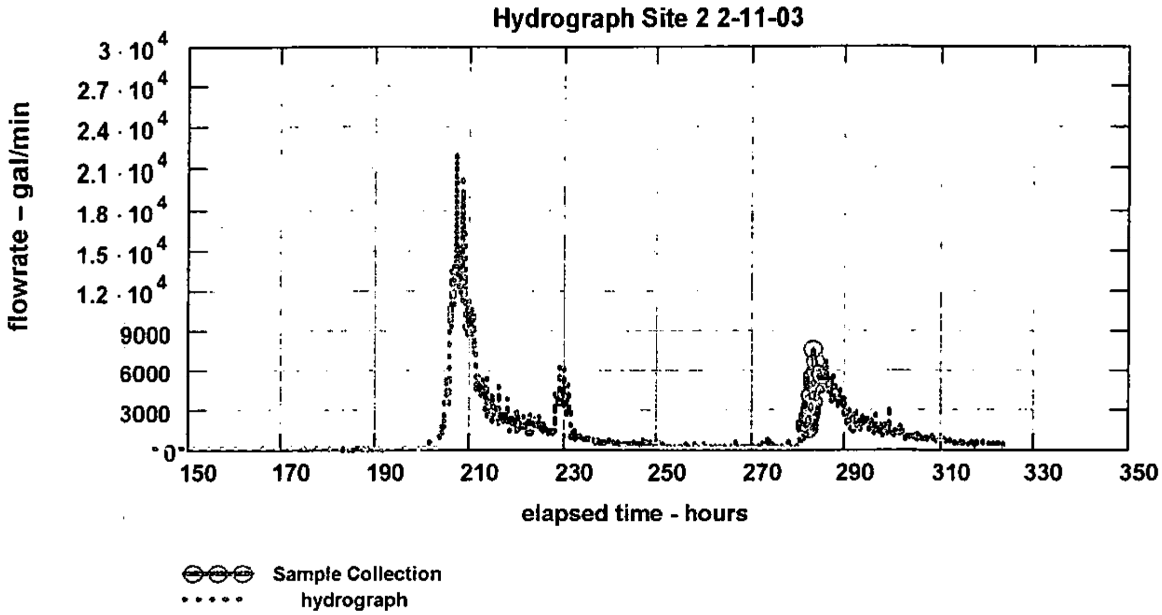
## Figure A-II-3
## Site 4
## 2-11-03

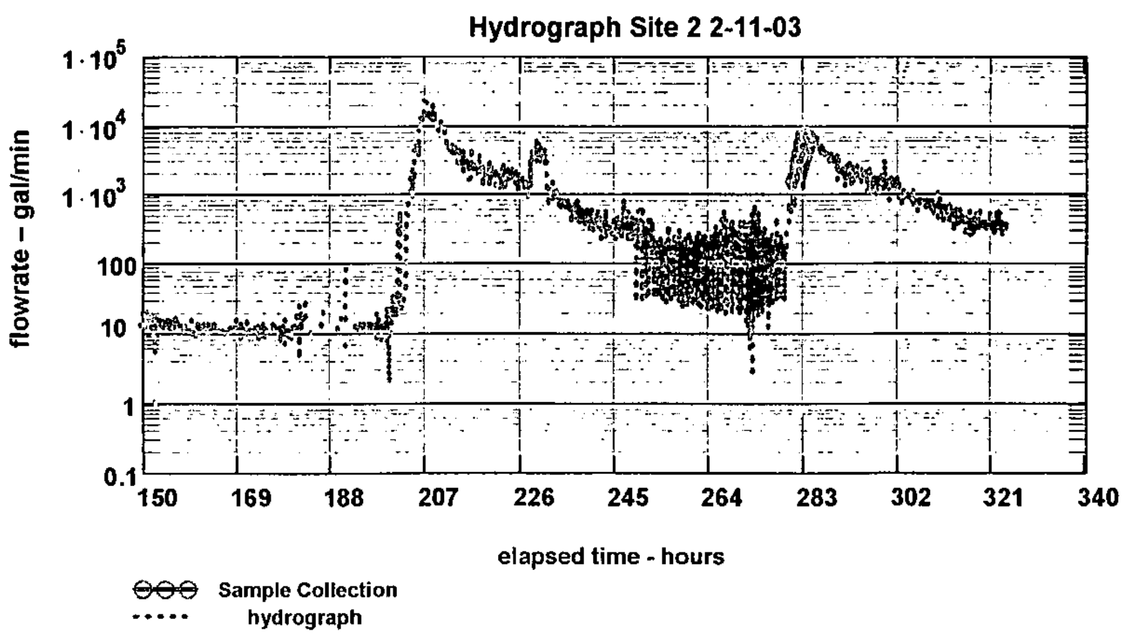



**Signal starts starts at 12:30 pm. on 2/9/2003, and ends at 9:00 a.m on 2/11/2003.**

**Figure A-II-3**
**Site 2**
**2-11-03**

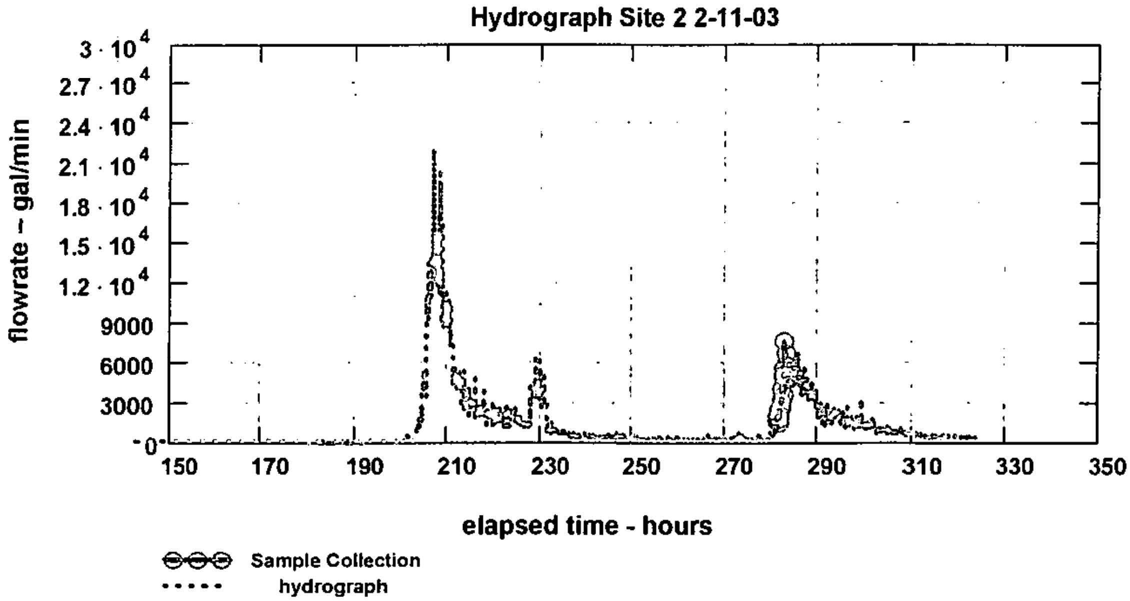



**Signal starts at 9:18 p.m. on Jan. 28, and ends at 9:24 pm on Feb. 11.**

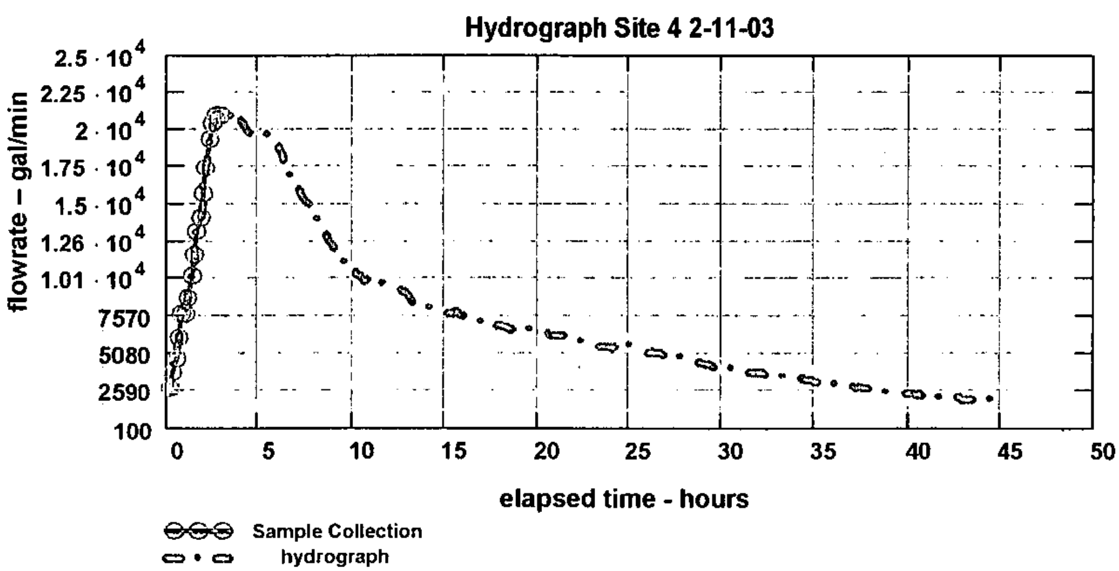
# Figure A-II-3

**Sites 2 and 4**
**2-11-03**



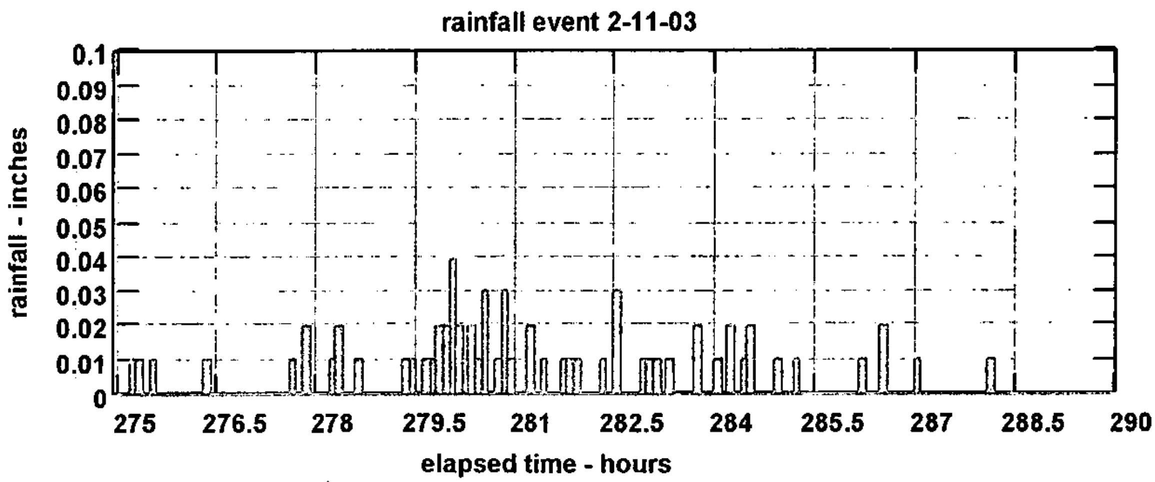

**Rain 2.53 inches**

**Site 2 Signal starts at 9:18 p.m. on Jan. 28, and ends at 9:24 pm on Feb. 11, 2003. First Peak 3 am 2-6-03, last peak 6 am 2-9-03. <u>Only last peak corresponds to flow at Site 4.</u>**




**Site 4 Signal starts at 12:30 pm. on 2/9/2003, and ends at 9:00 a.m on 2/11/2003.**
**Peak at 4:30 pm 2-9-03**

**Rain : 0.4 in between jan 29th 4:54 am and Jan 29 th 11:06 am**
**0.24 in between Feb 3, 8:30 am and Feb 3, 8:54 pm**
**1.16 in between Feb 5, 8:12 pm and Feb 6, 4:18 pm**

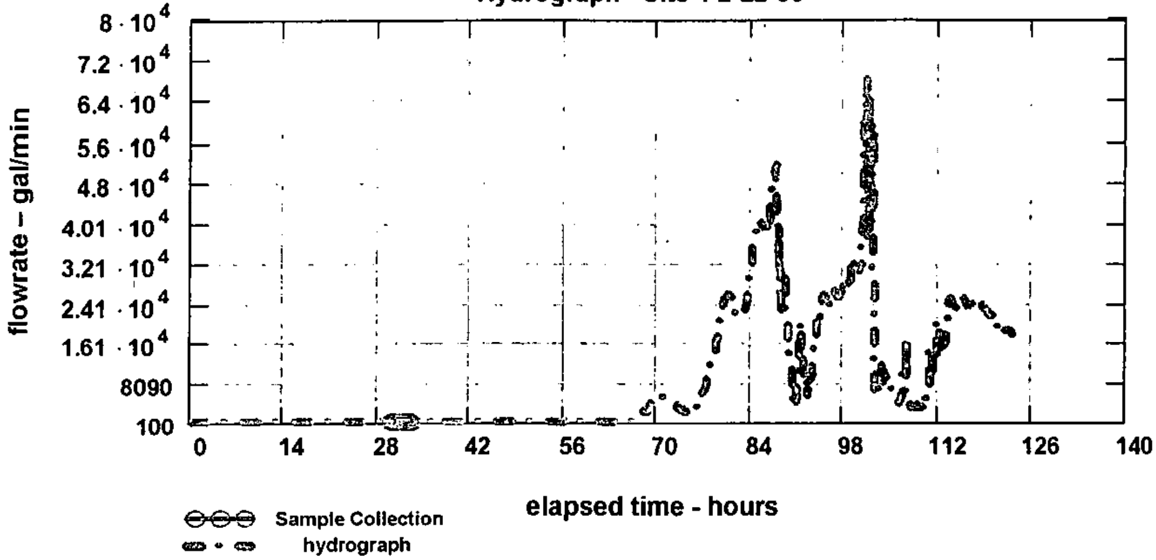



**0.64 inches between Feb 9th 8:24 am and Feb 9th 9:36 pm, 11 hours**

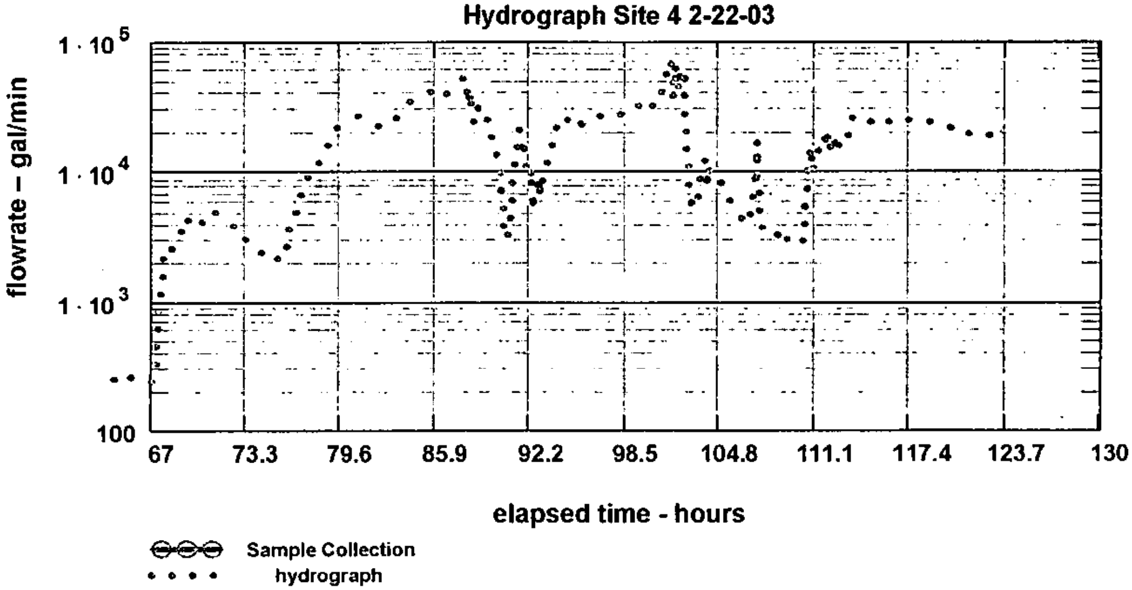
## Figure A-II-4

**Site 4**
**2-22-03**

**Hydrograph - Site 4 2-22-03**



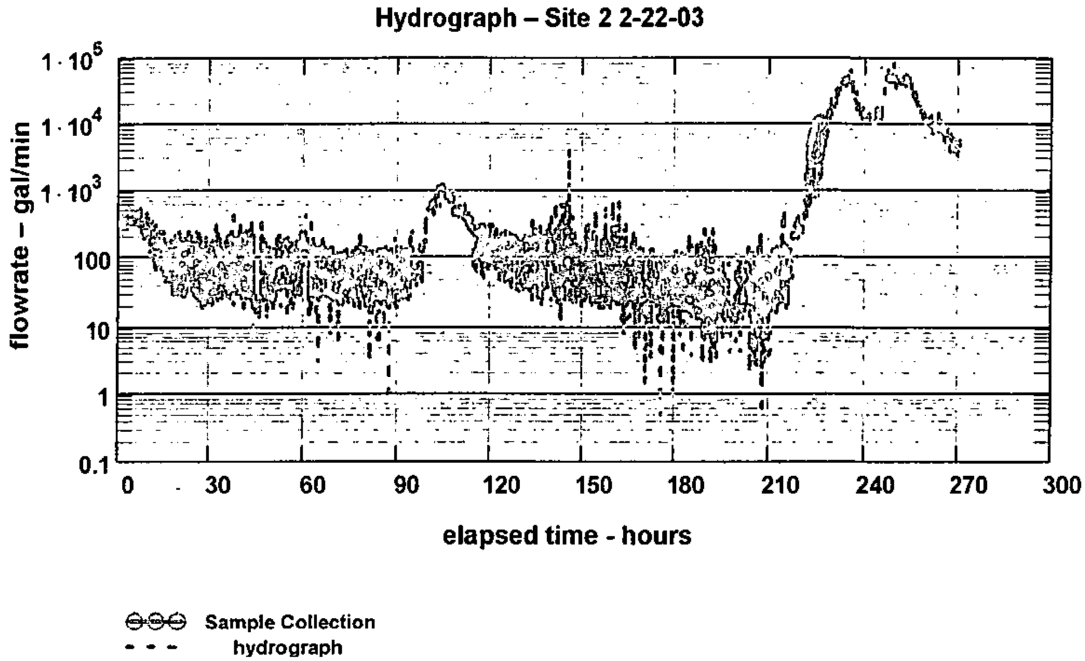

**Hydrograph Site 4 2-22-03**

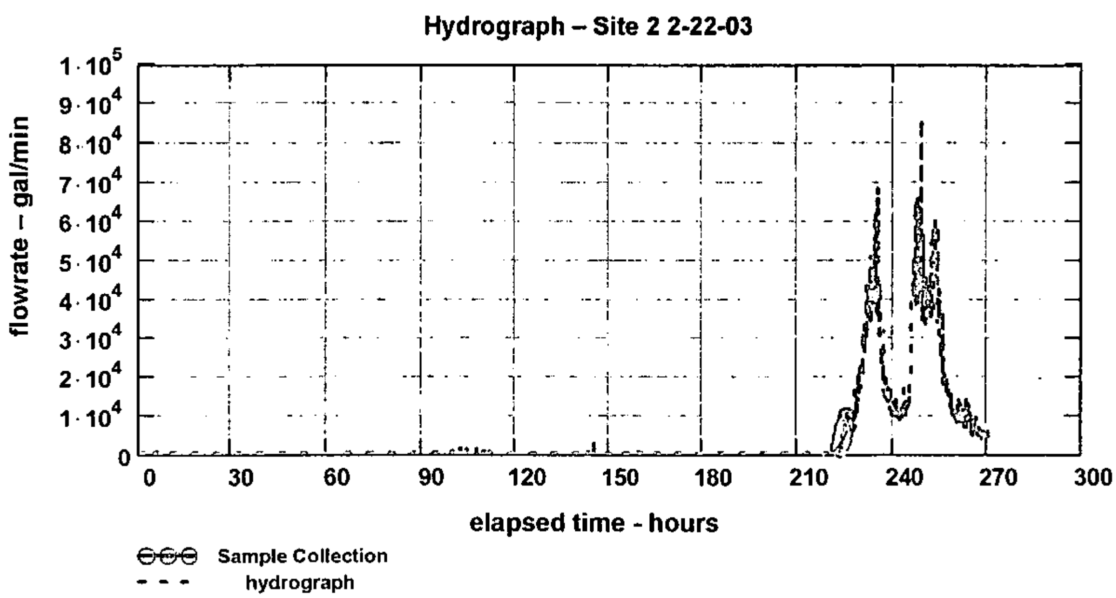



**Signal starts at 10:00 am. on 2/17/2003, and ends at 1:20 p.m on 2/22/2003**

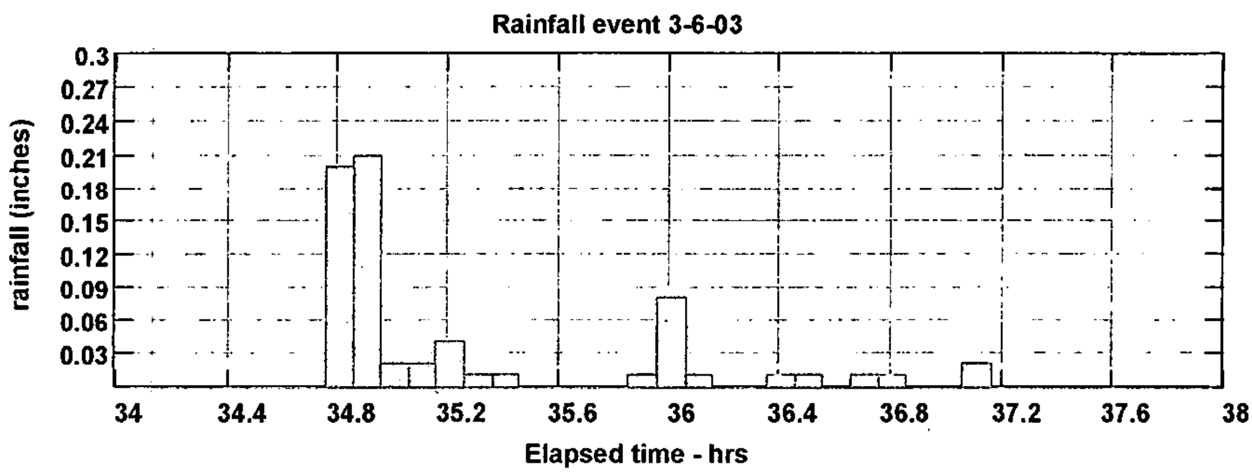
## Figure A-II-4

### Site 2
### 2-22-03



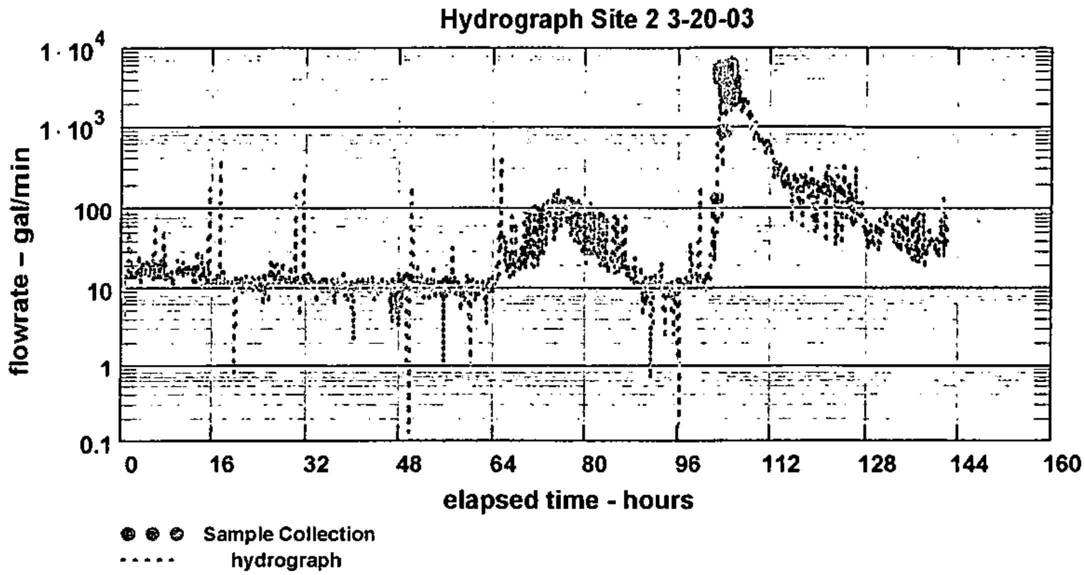
## Figure A-II-5

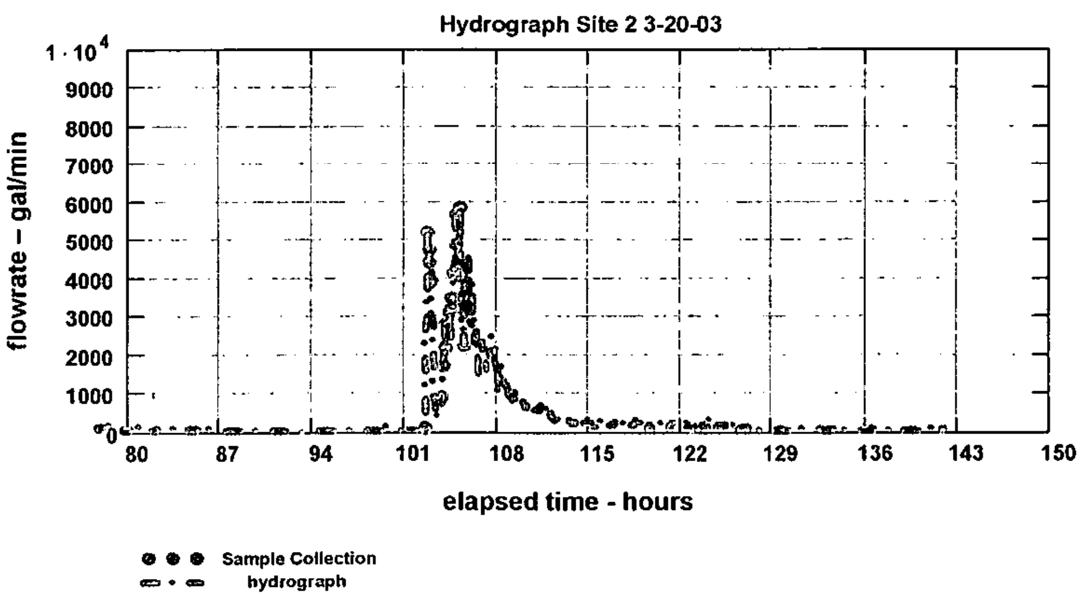



0.65 inches between March 5 at 7:42 pm and March 5 at 10:06 pm
2 hours

## Figure A-II-6

## Site 2
## 3-20-03

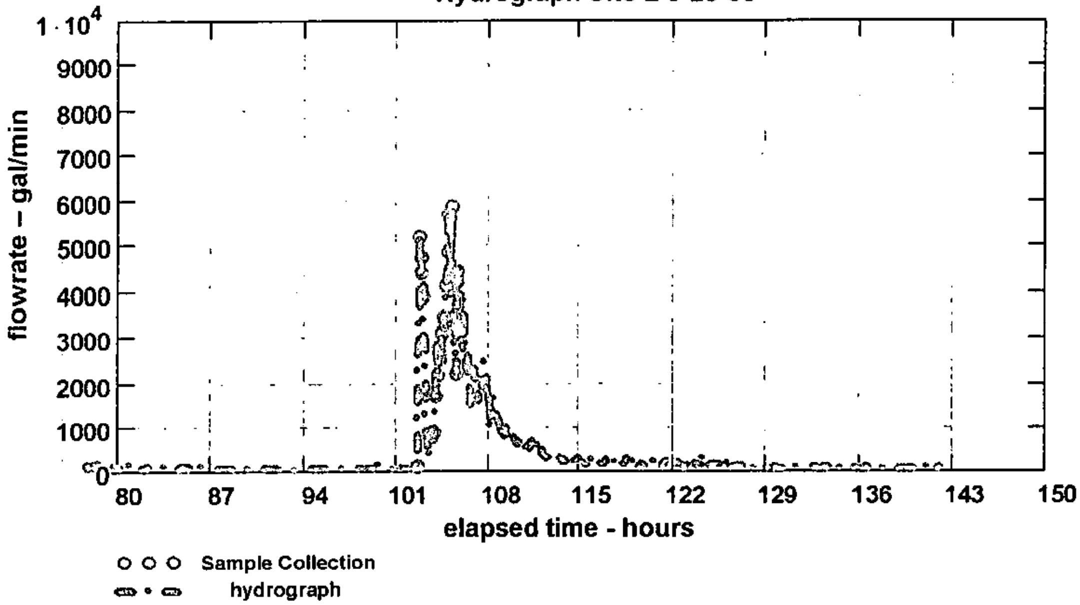


## Figure A-II-6

**Sites 2 and 4**
**3-20-03**

**Hydrograph Site 2 3-20-03**




**Site 2 The continous flow starts at 11:06 a.m. on March 14, and ends at 9:06 am on March 20.**
**Peak at 9 pm on 3-18-03**

**Site 4 The continous flow starts at 10:40 am. on 3/14/2003, and ends at 9:00 am on 3/20/2003.**
**Peak at 6:30 pm 3-18-03**

**0.15 inches between March 17, at 3 am and March 17 at 9 am**

**Hydrograph Site 4 3-20-04**

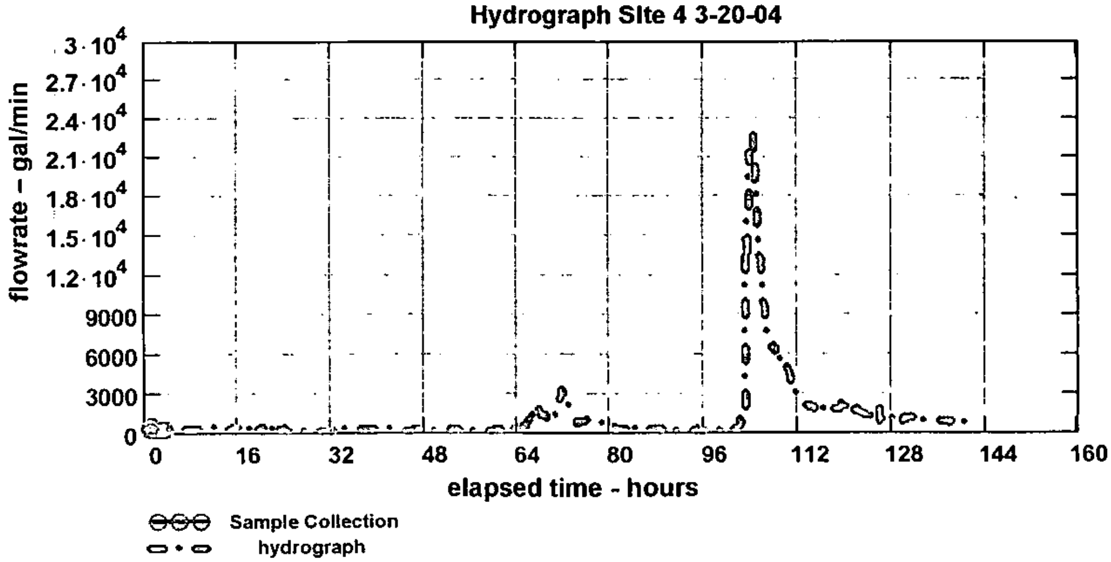
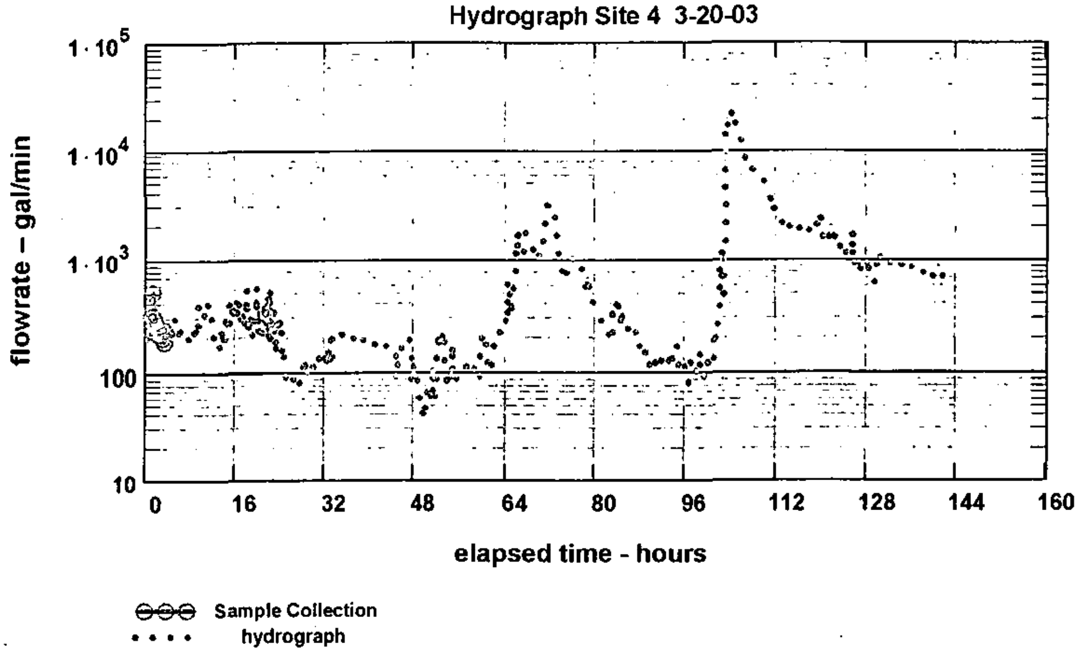
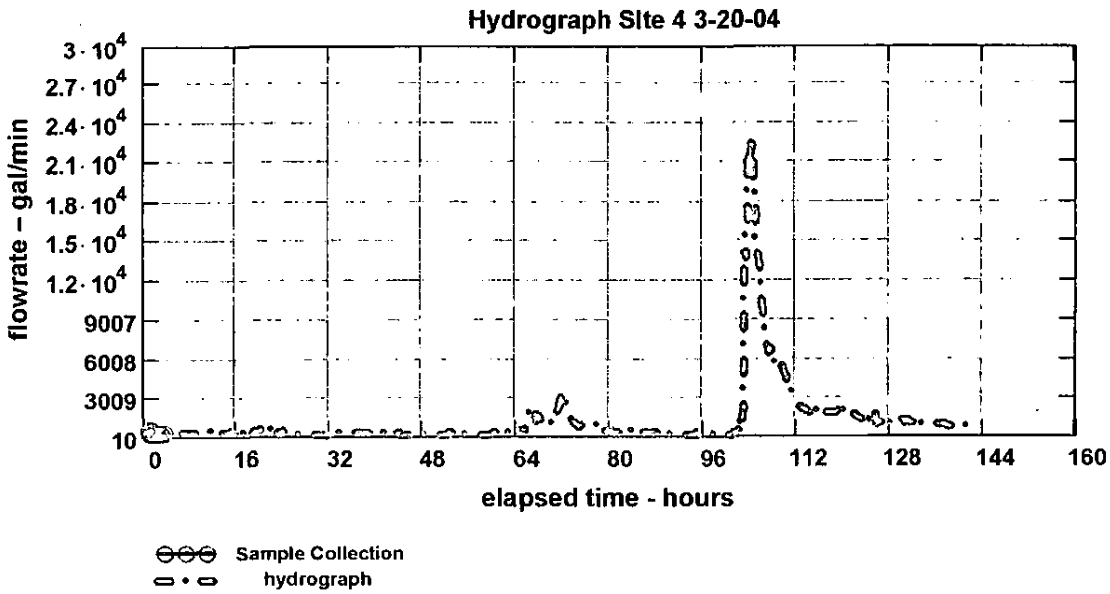


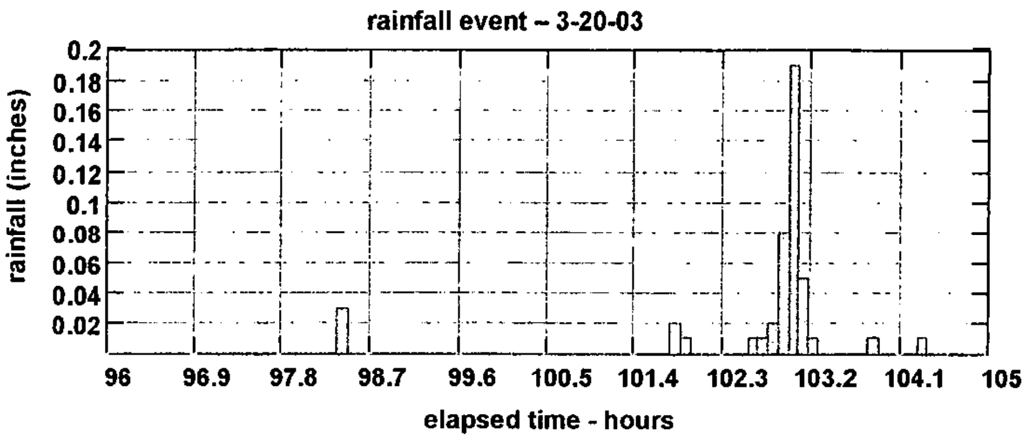
**Figure A-II-6**

**Site 4**
**3-20-03**



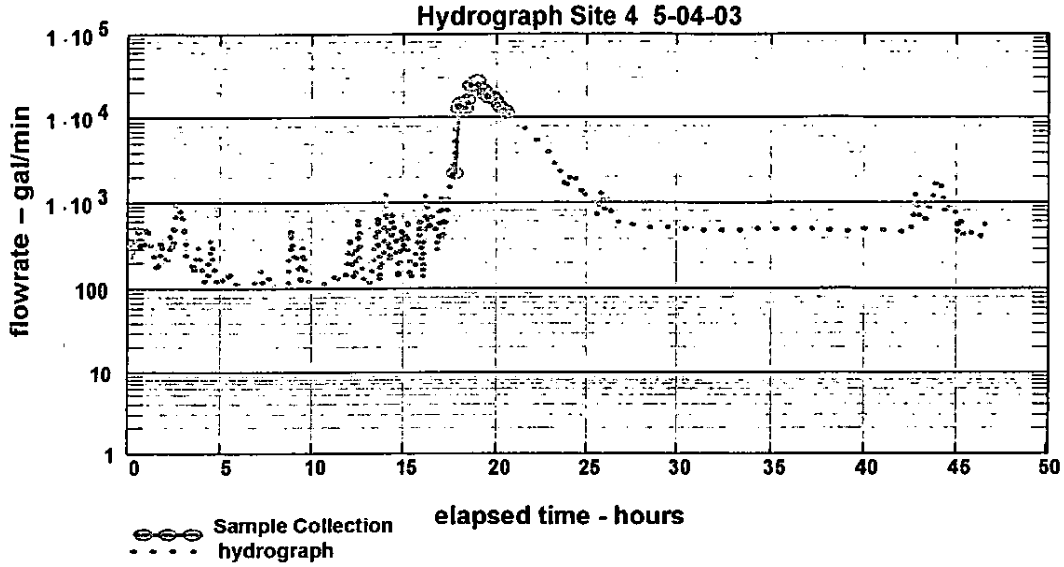
## Figure A-II-6

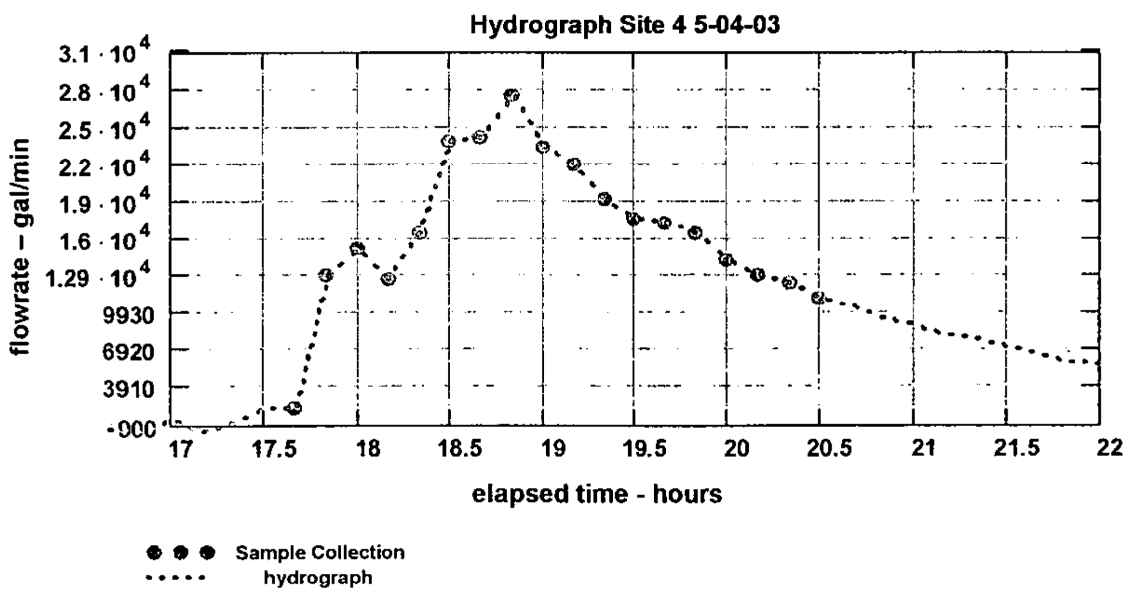



**0.39 inches rain between March 18, 4:48 pm and March 18, 7:54 pm**
**3 hours**

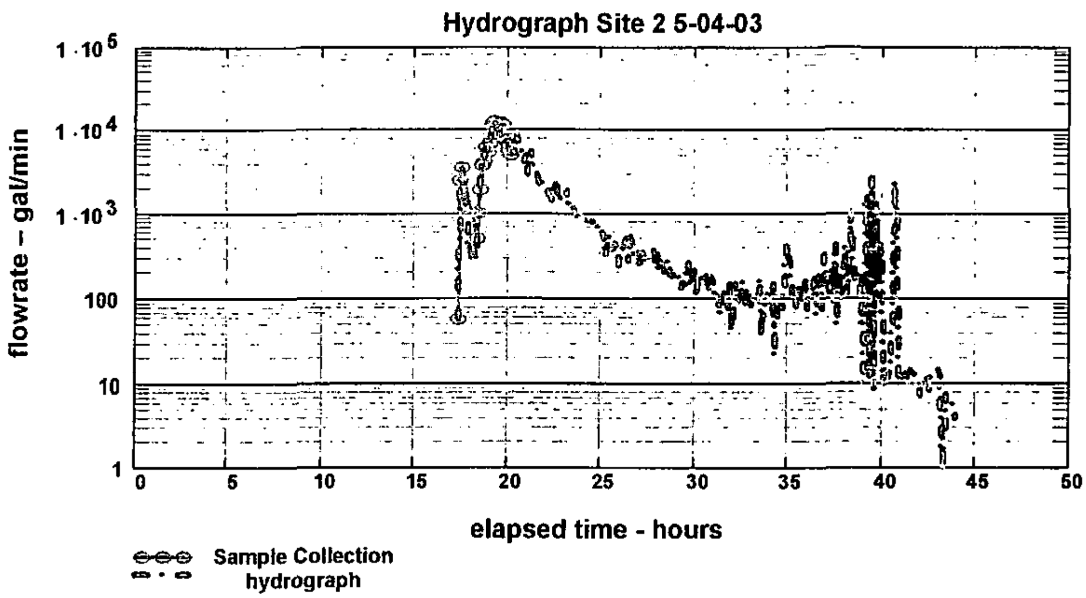
## Figure A-II-7

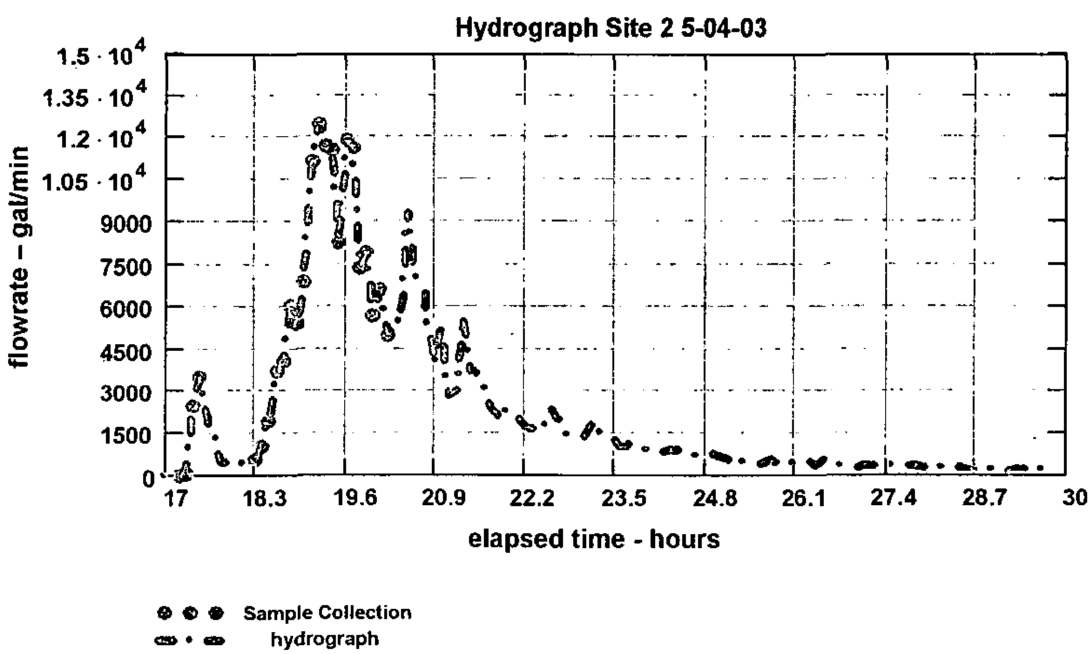
**Site 4**
**5-04-03**



# Figure A-II-7
## Site 2
## 5-04-03



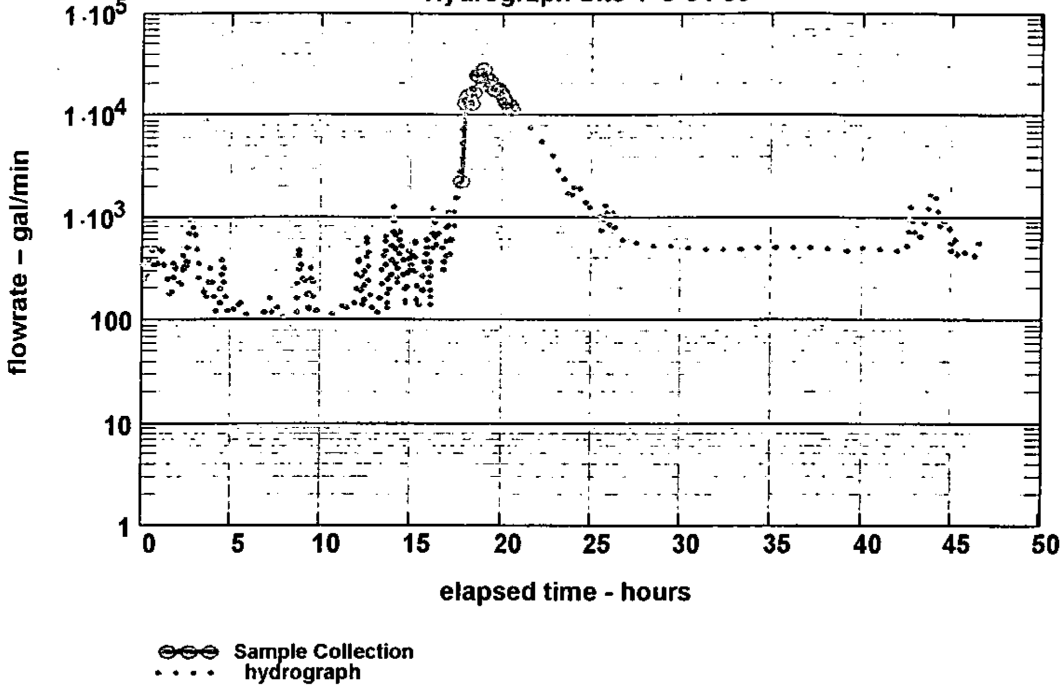




Site 2 signal starts at 9:42 a.m. on May 2, and ends at 8:06 am on May 4.

# Figure A-II-7

## Sites 2 and 4
## 5-04-03

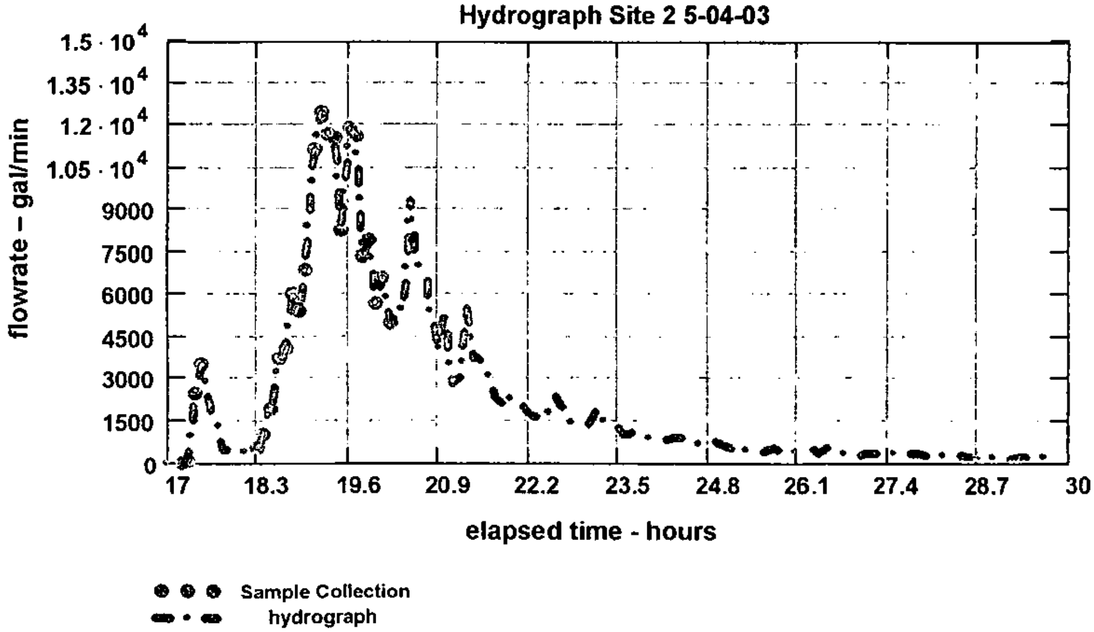
Hydrograph Site 4 5-04-03



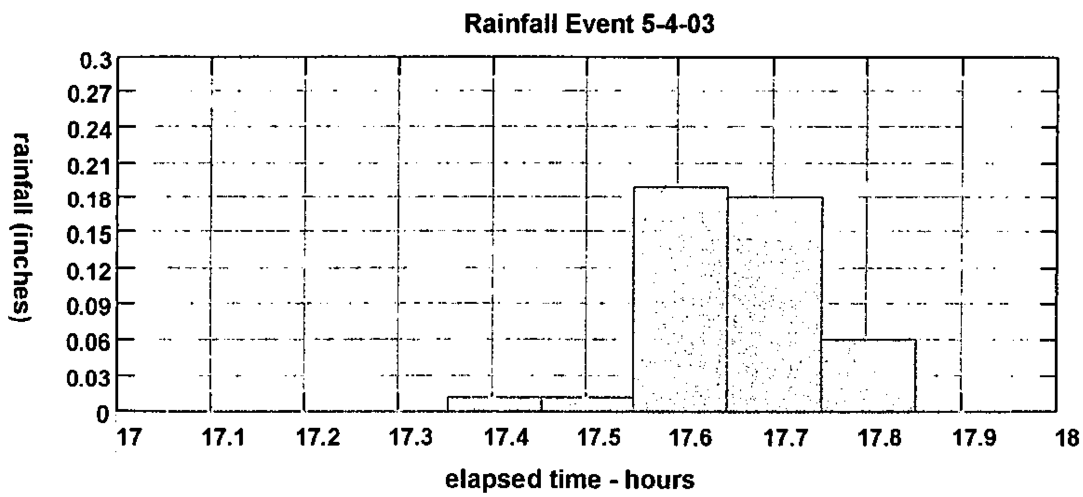

**Site 4 signal starts at 9:10 am. on 5/2/2003, and ends at 7:40 am on 5/4/2003. Peak at 5 am 5-3-03**

**Site 2 signal starts at 9:42 a.m. on May 2, and ends at 8:06 am on May 4. Peak at 6 am 5-3-03**

Hydrograph Site 2 5-04-03



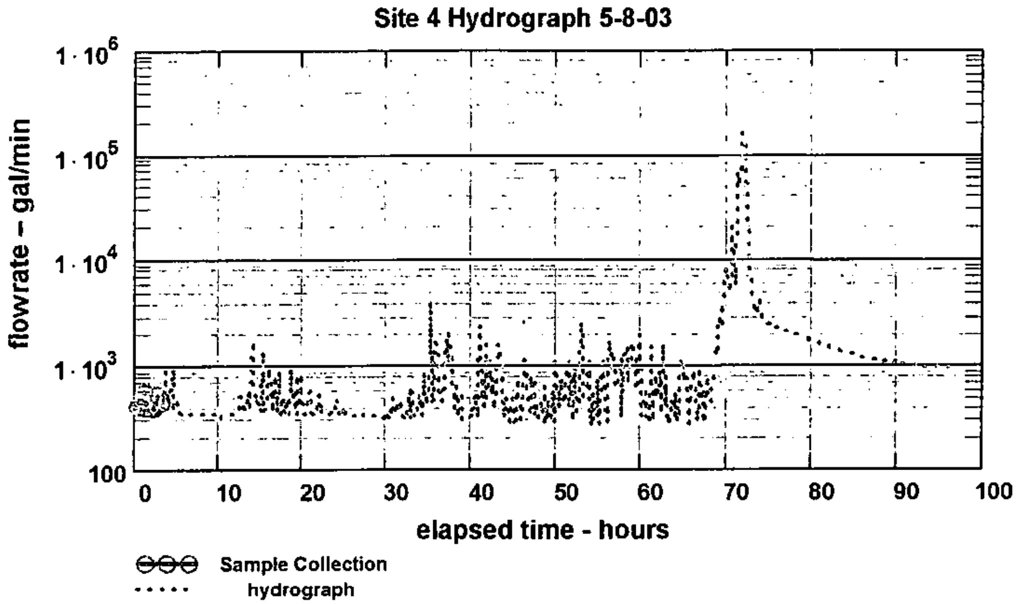
## Figure A-II-7



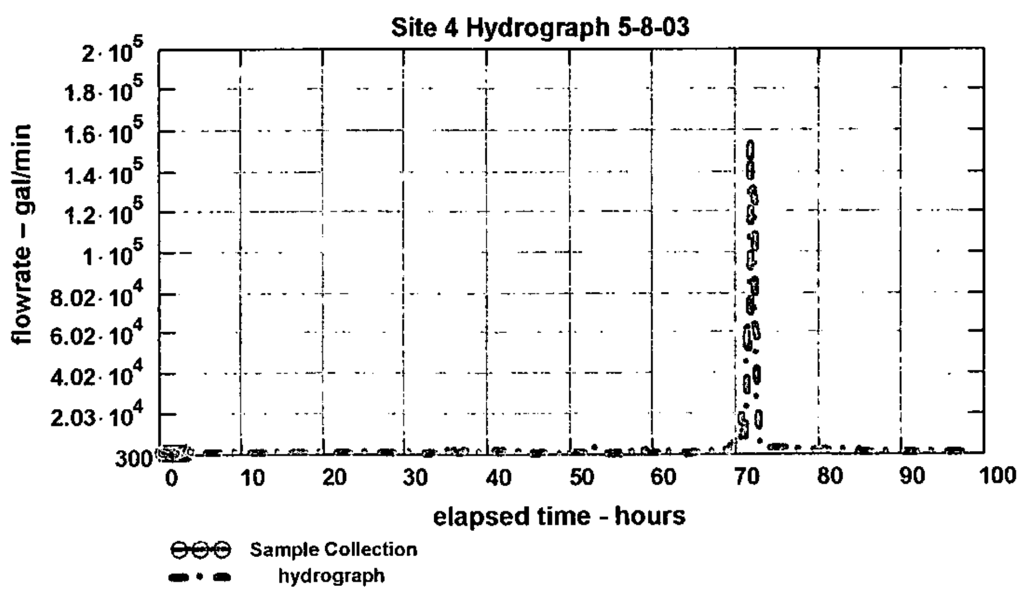

**0.46 inches rain between May 3 at 2:28 am and May 3 at 3:12 am, 0.5 hour**

## Figure A-II-8

**Site 4**
**5-8-03**

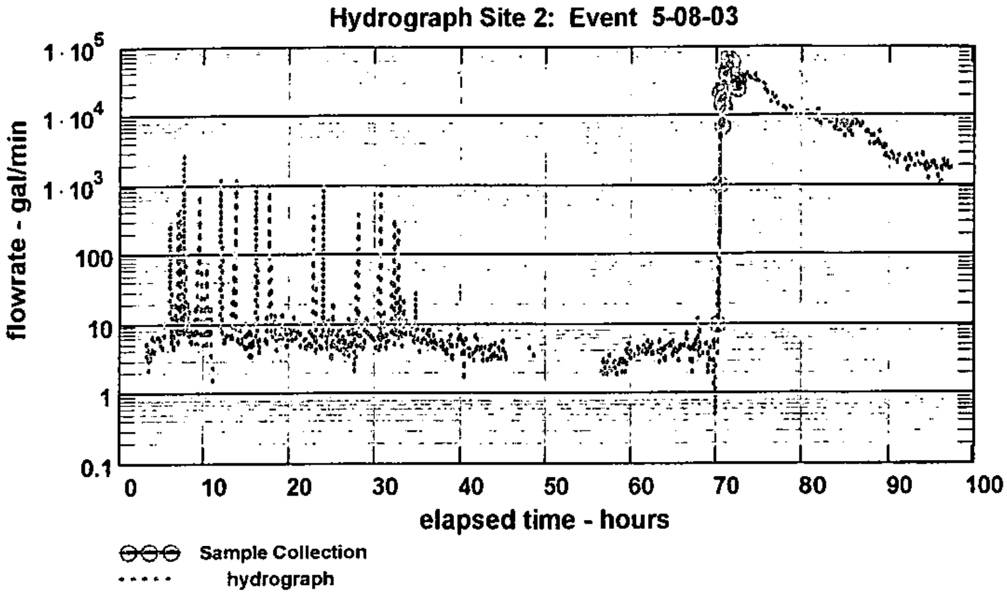



Flow starts at 8:00 am. on 5/4/2003, and ends at 9:10 am on 5/8/2003.

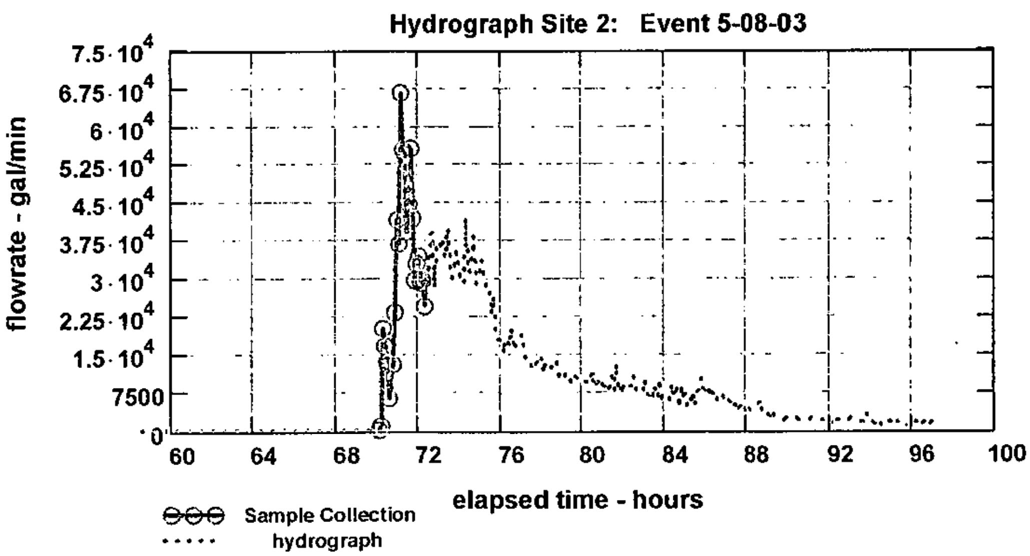


# Figure A-II-8

## Site 2
## 5-08-03




**Site 2 - Signal starts at 8:24 a.m. on May 4, and ends at 9:48 am on May 8.**

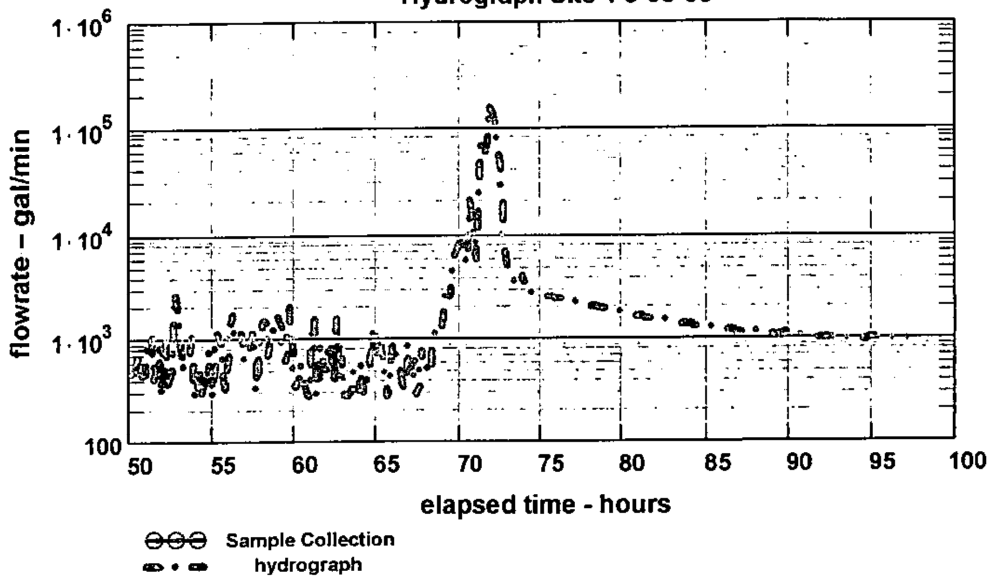


# Figure A-II-8

**Sites 2 and 4**
**5-08-03**

**Site 4 The continous flow starts at 8:00 am. on 5/4/2003, and ends at 9:10 am on 5/8/2003**
**Peak at 8 am 5-7-03.**

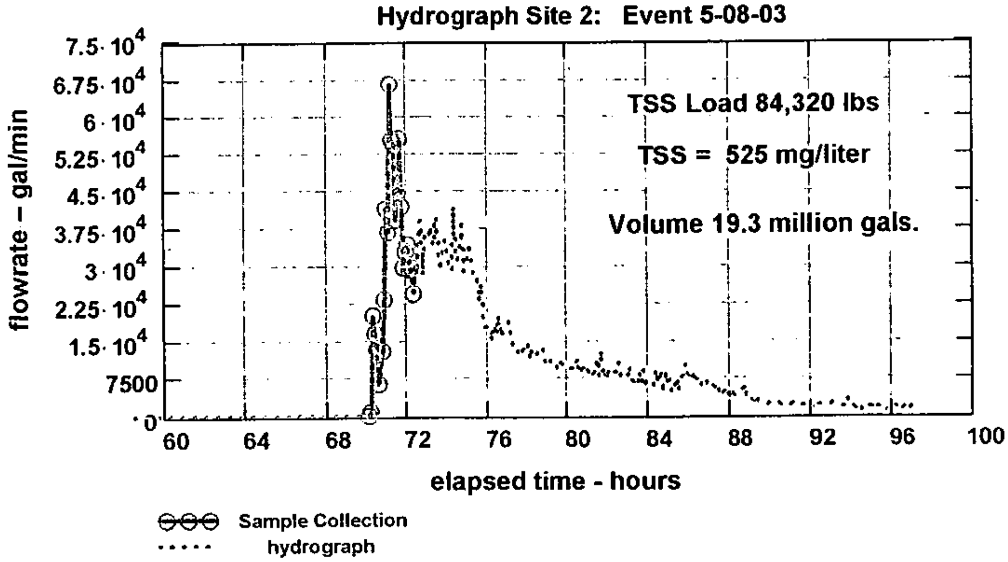
**Hydrograph Site 4 5-08-03**



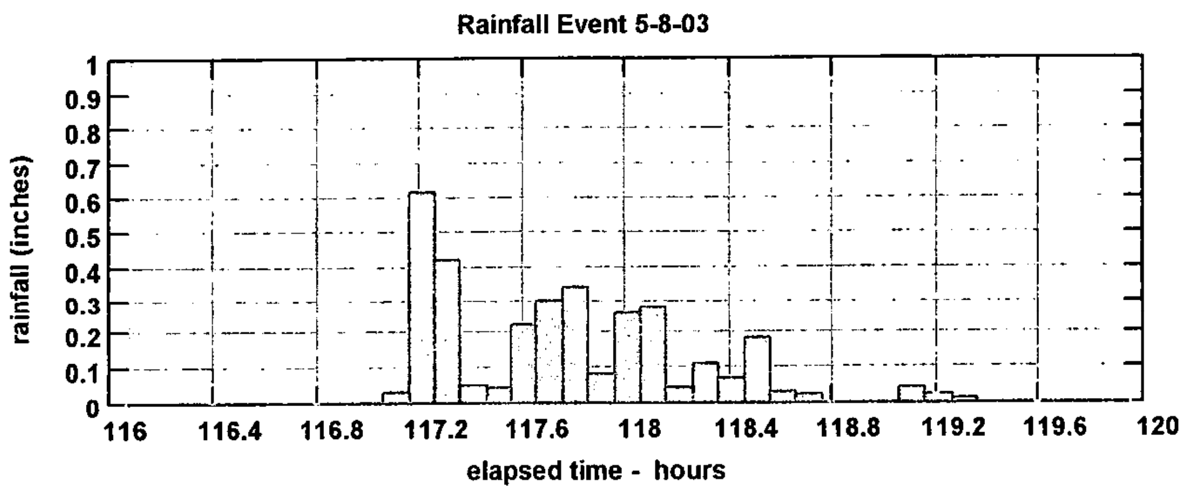

**0.37 inches rain between May 3 at 2:48 am and May 3 at 3:12 am**

**Site 2 - The continous flow starts at 8:24 a.m. on May 4, and ends at 9:48 am on May 8, 2003.**
**Peak at 8:30 am 5-7-03**

**Hydrograph Site 2: Event 5-08-03**

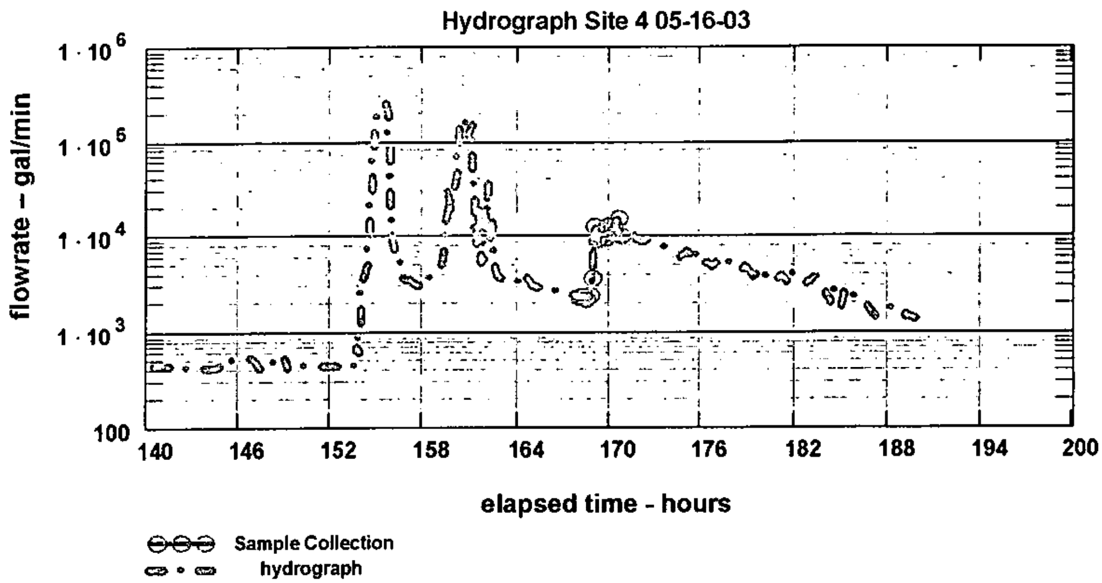


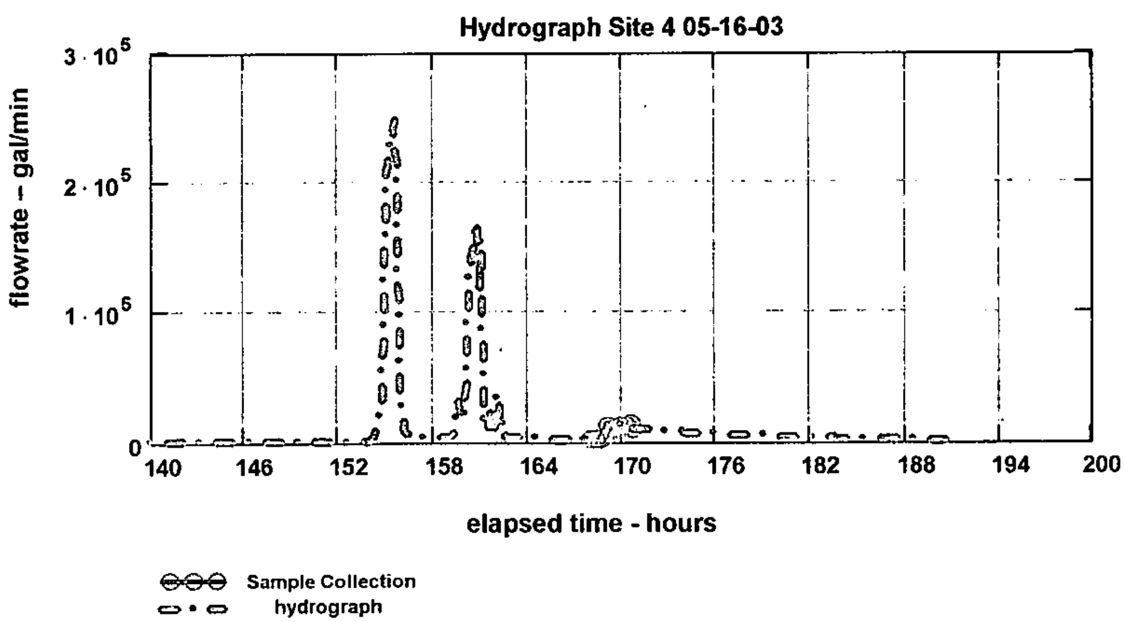
## Figure A-II-8



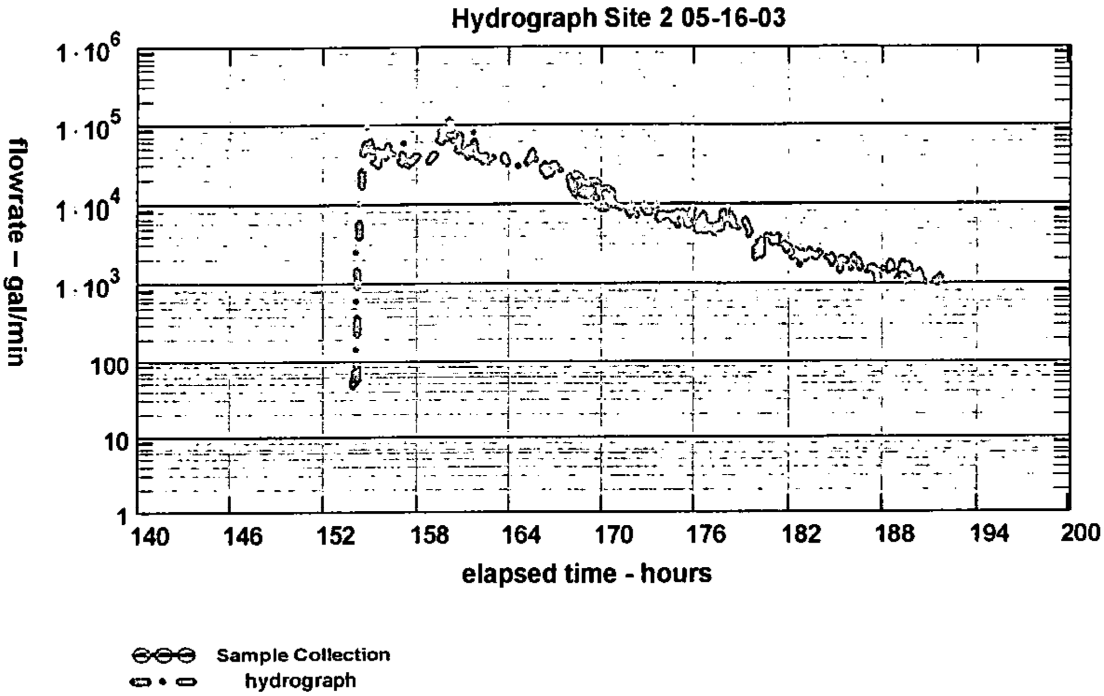

3.15 inches rain between May 7 at 6:24 am and May 7 at 8:42 am,
3 hours

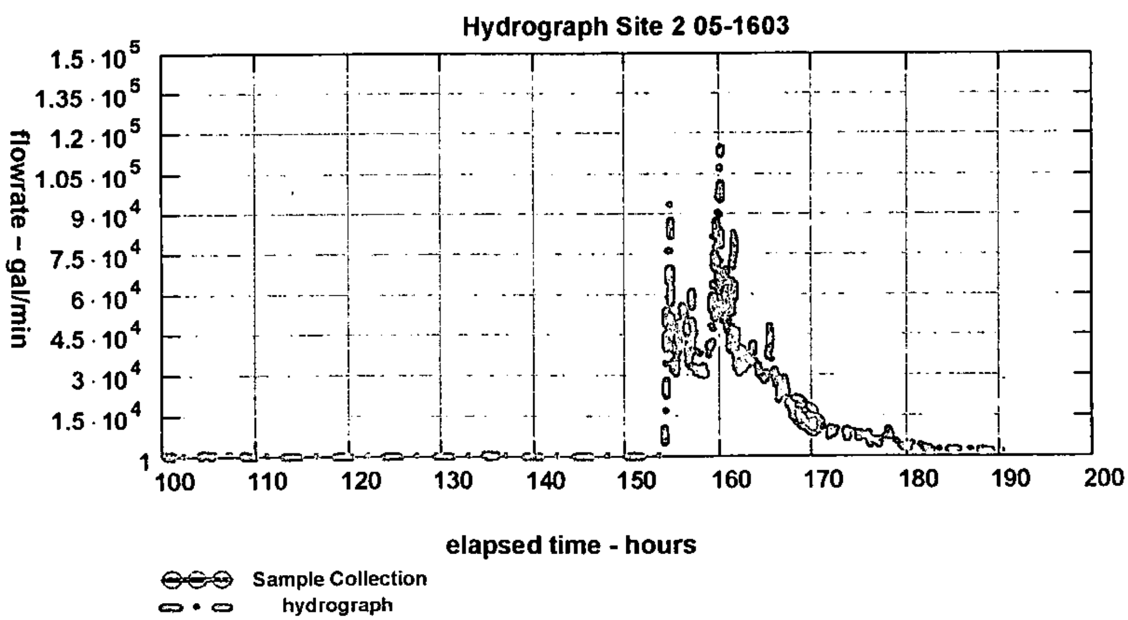
## Figure A-II-9
## Site 4
## 5-16-03



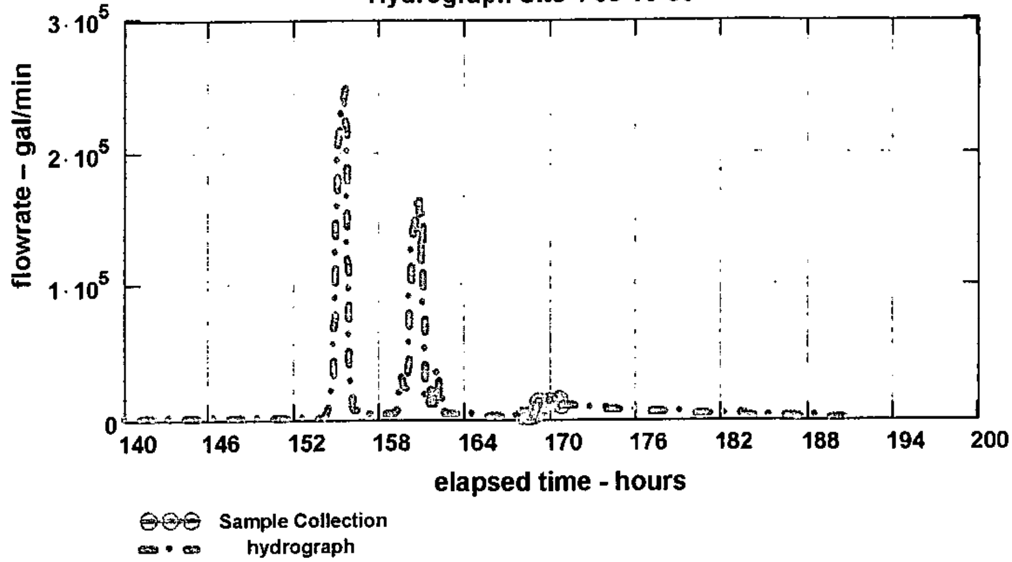
# Figure A-II-9
## Site 2
## 5-16-03



# Figure A-II-9
## Sites 2 and 4
## 5-16-04

Hydrograph Site 4 05-16-03




**Site 4 Signal starts at 9:30 am. on 5/8/2003, and ends at 8:10 am on 5/16/2003. Peak 1 at 7:45 pm 5-14-03, peak 2 at 1:30 am 5-15-03**

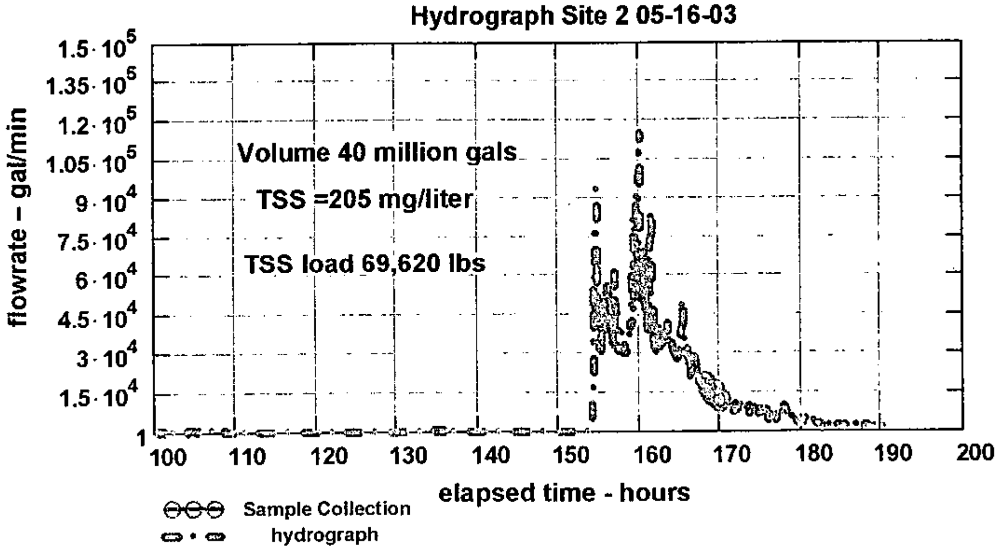
**0.44 in between May 3 at 2:48 am and May 3 at 3:12 am**

**3.15 inches between May 7 at 6:24 am and May 7 at 8:42 am**

**0.38 in between May 11 at 5:18 am and May 11 7:12 am**

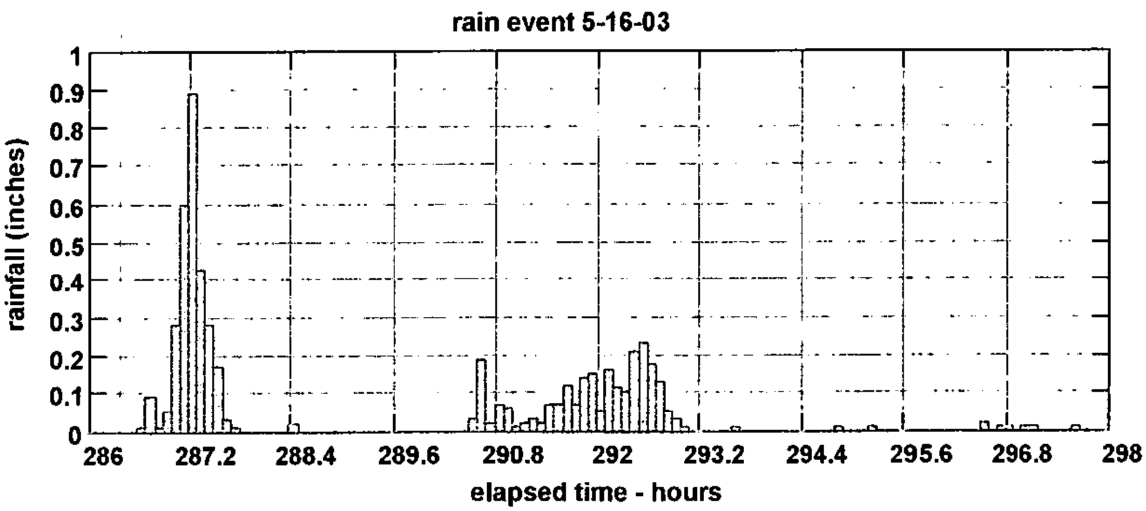
5.[illegible] inches between May 1[illegible] at 7:38 pm and May [illegible] am, [illegible]

Hydrograph Site 2 05-16-03



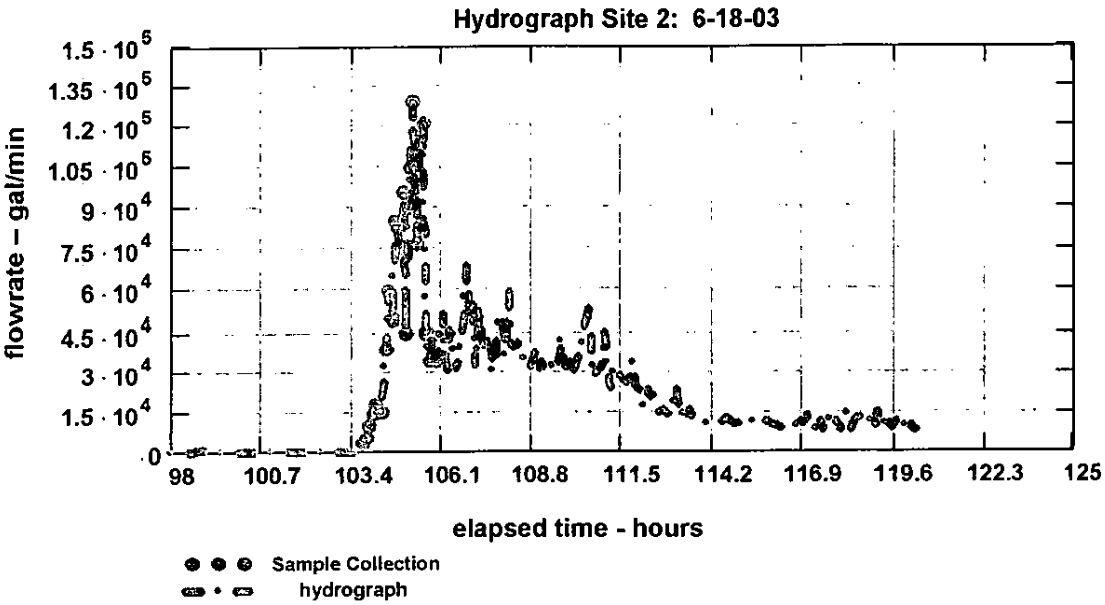

**Site 2 signal starts at 9:54 a.m. on May 8, and ends at 9:24 am on May 16. Peak 1 at 10 pm 5-14-03, peak 2 at 2 am 5-15-03**

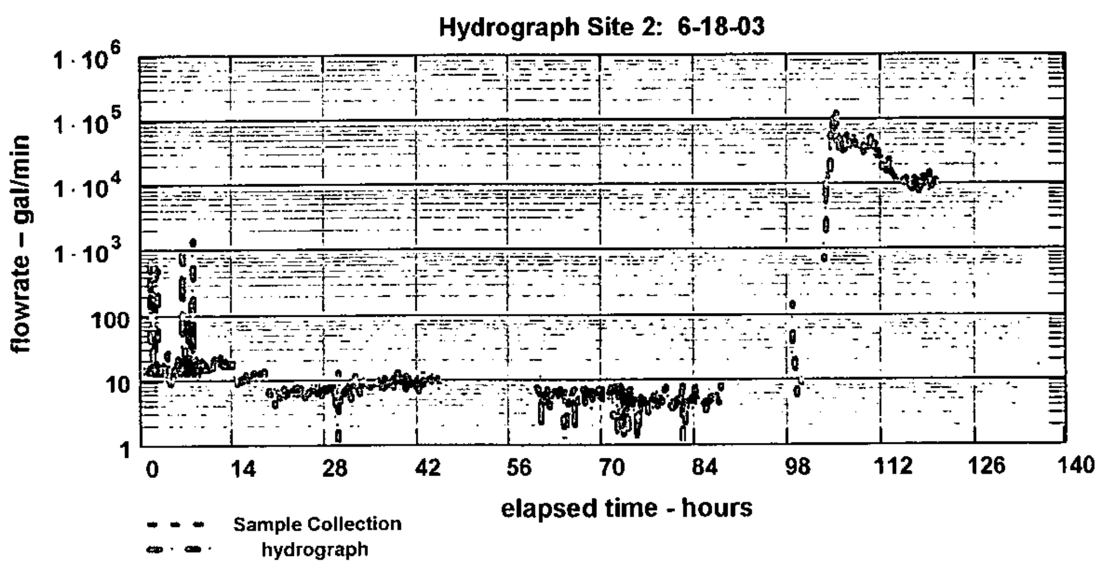
**Figure A-II-9**



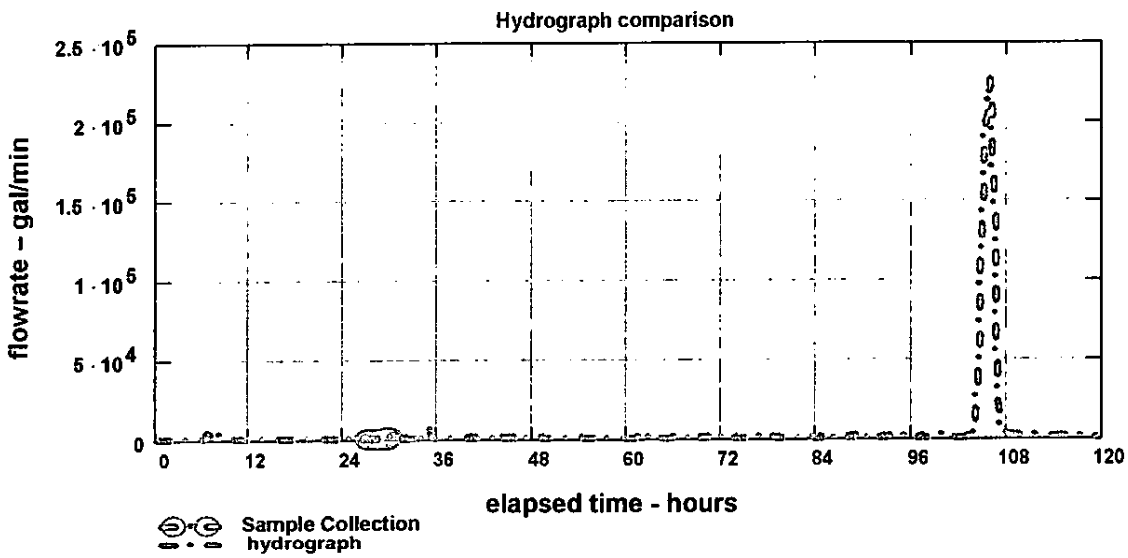

5.3 inches between May 14 at 7:36 pm and May 15 at 6:42 am,
12 hours

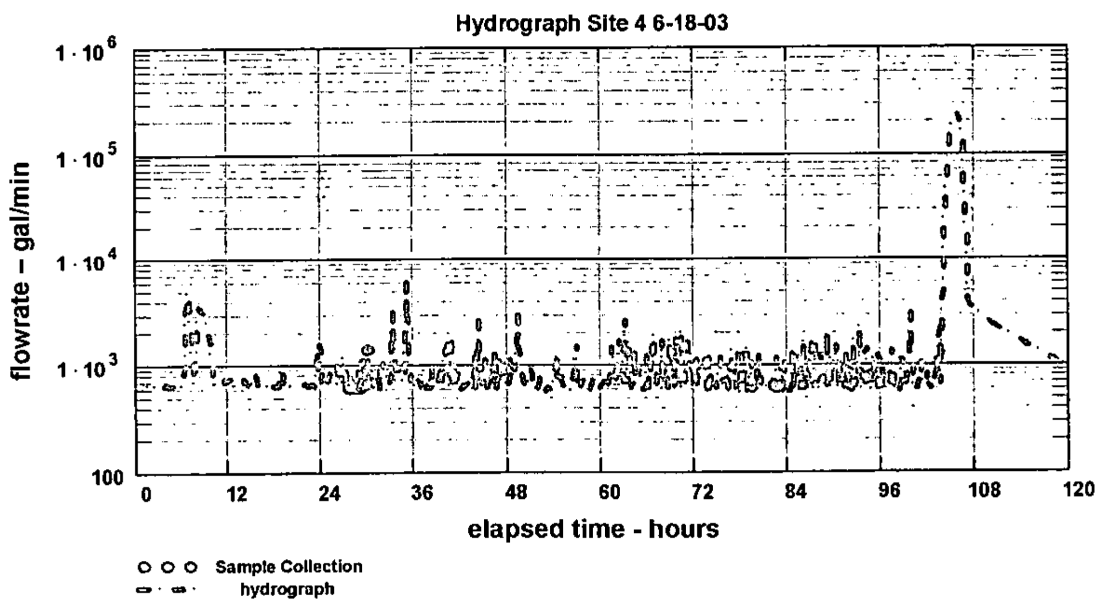
**Figure A-II-10**
**Site 2**
**6-18-03**



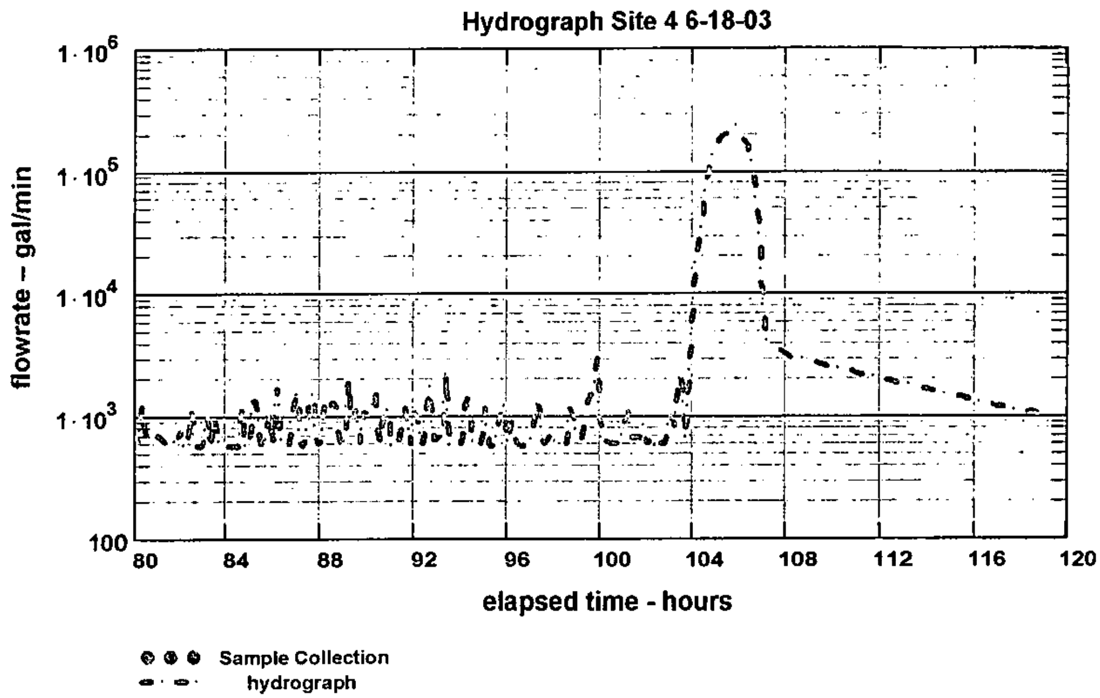
## Figure A-II-10
## Site 4
## 6-18-04

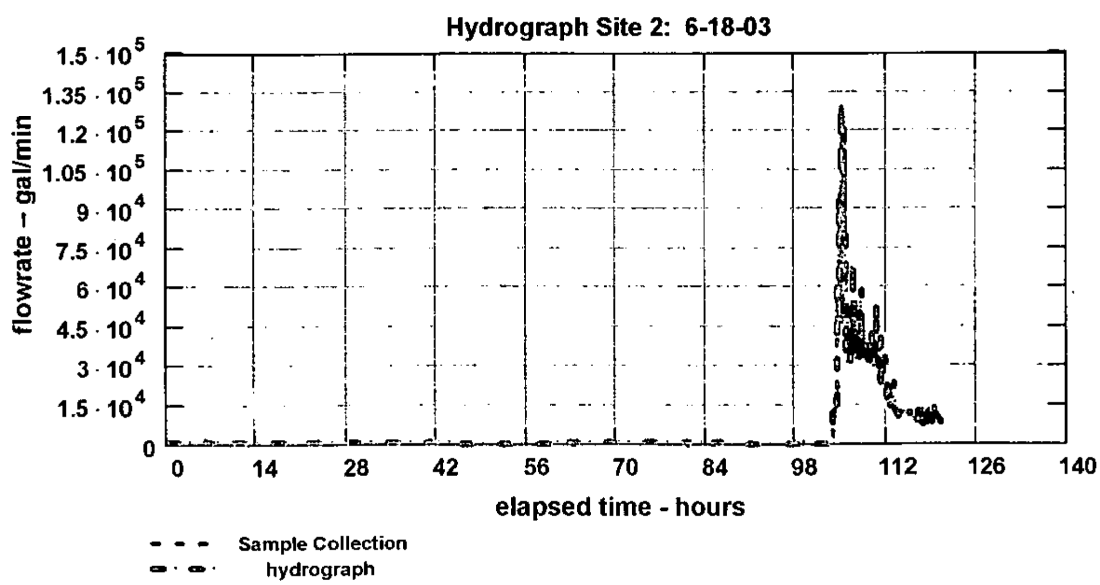


## Figure A-II-10
## Site 2 and 4
## 6-18-03

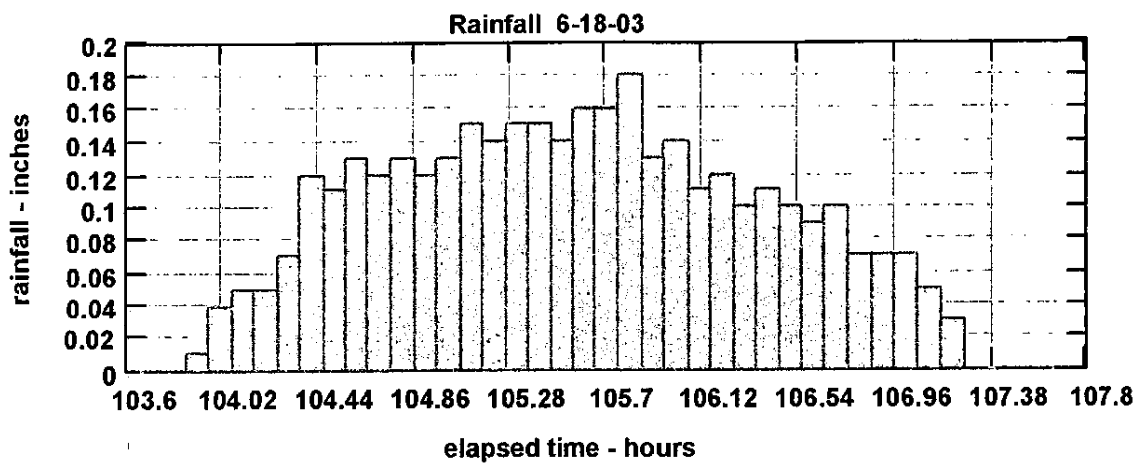
**Site 4 The continous flow starts at 8:31 am. on 6/13/2003, and ends at 8:31 am on 6/18/2003, peak at 5:30 pm 6-17-04**



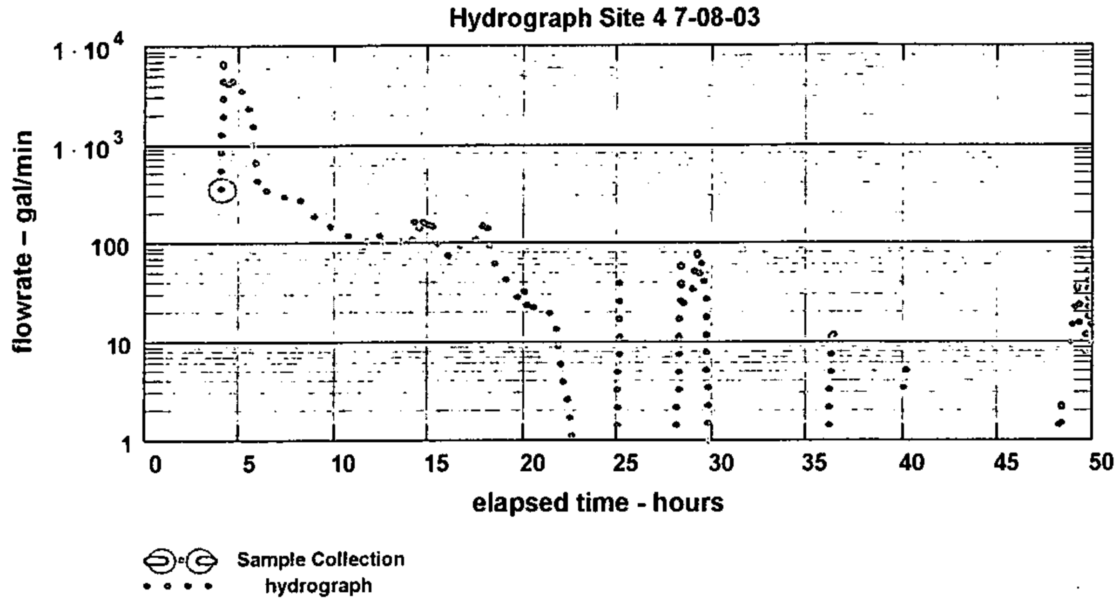

**Site 2-The continous flow starts at 8:54 a.m. on June 13, and ends at 9:12 am on June 18, peak at 7 pm 6-17-04**

## Figure A-II-10

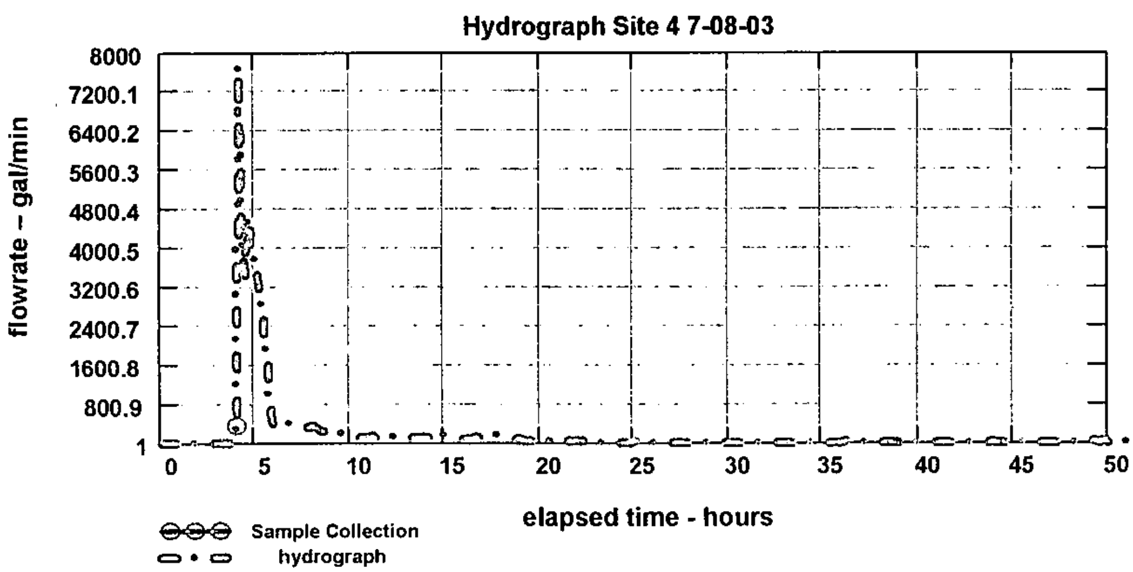



4.14 inches rain between June 17, 11:24 am and June 17, 11:42 pm, 12 hours

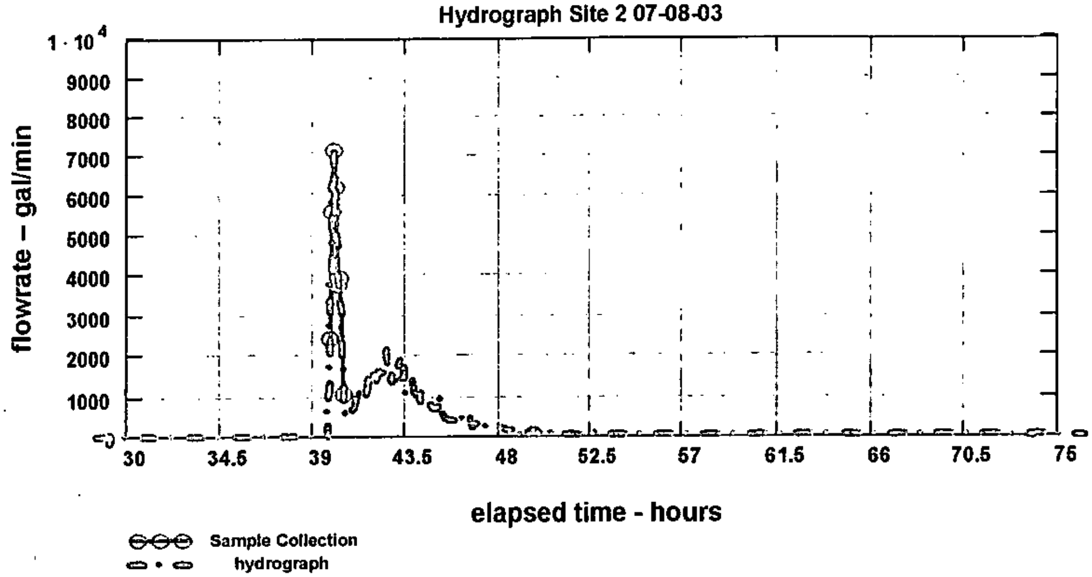
# Figure A-II-11
# Site 4
# 7-08-03




**Site 4-Signal starts at 8:20 am. on 6/26/2003, and ends at 8:20 am on 7/8/2003. Peak at 12:20 pm 6-26-03**



## Figure A-II-11
## Site 2
## 7-08-03



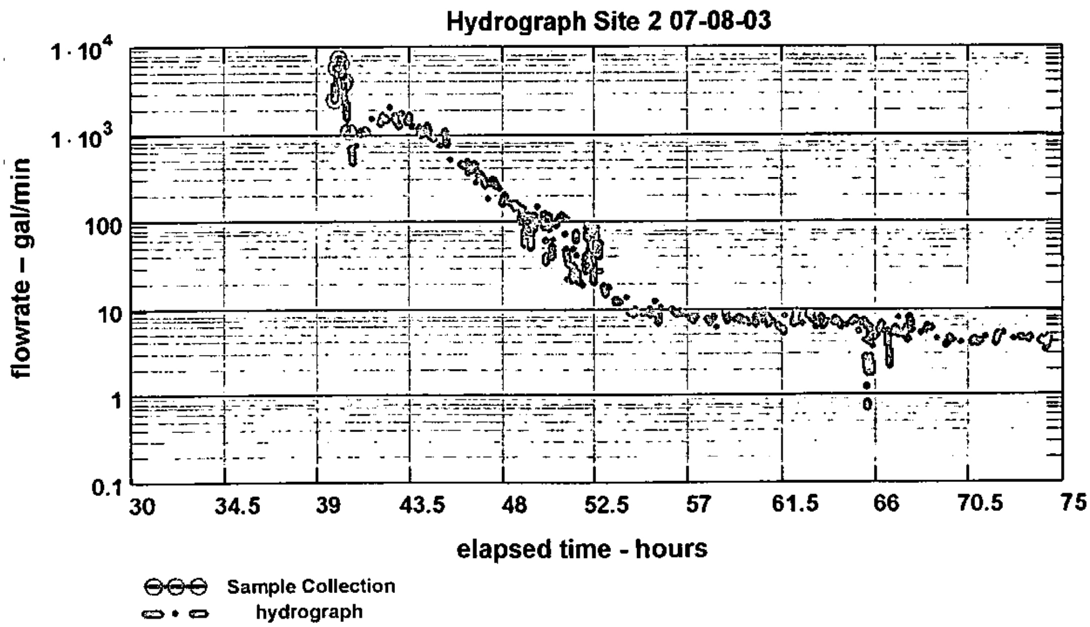
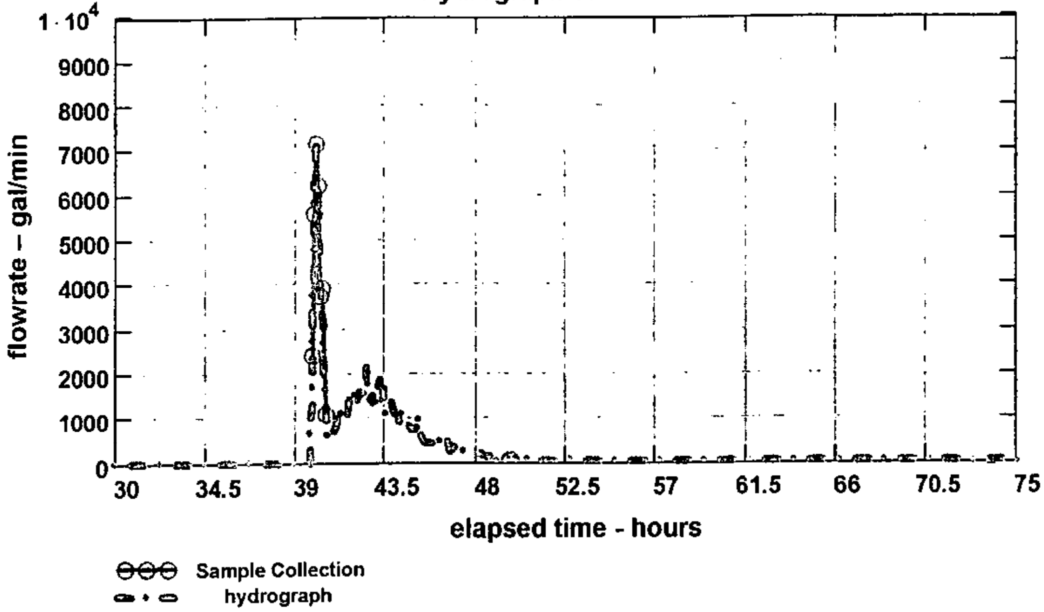



Figure A-II-11
sites 2 and 4
7-08-04

Hydrograph Site 2 07-08-03

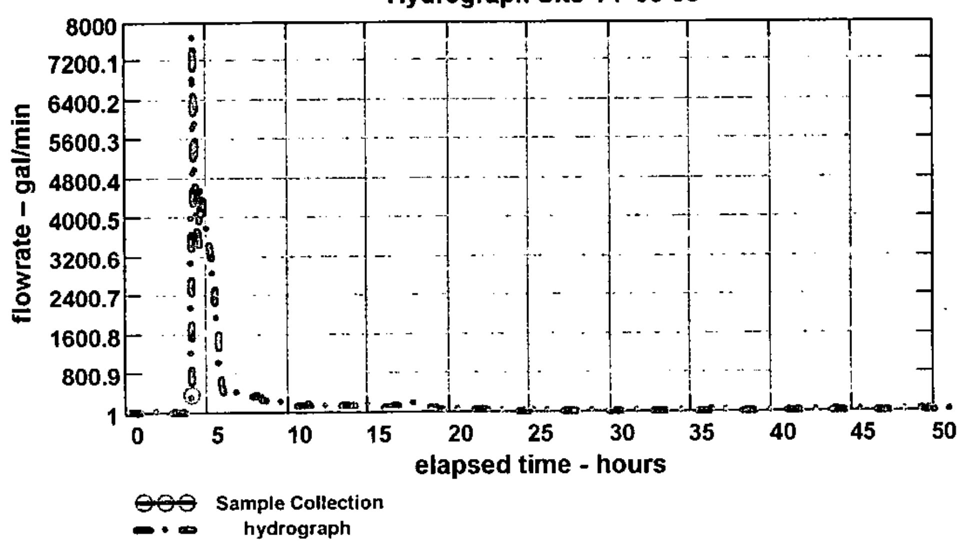



0.91 inches between June 26 and 12:42 pm and June 26 [illegible] pm, [illegible]

**0.27 in between July 2, 12:42 pm and July 2, 4:48 pm**

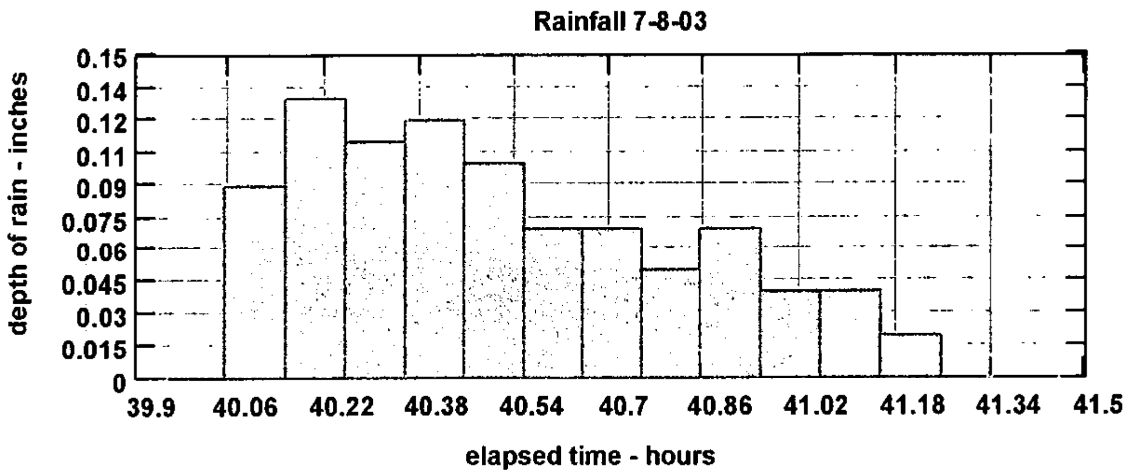
**Site 2 The continous flow starts at 8:42 p.m. on June 24, and ends at 8:48 am on July 08, 2003. Peak at 1:45 pm 6-26-03**

Hydrograph Site 4 7-08-03



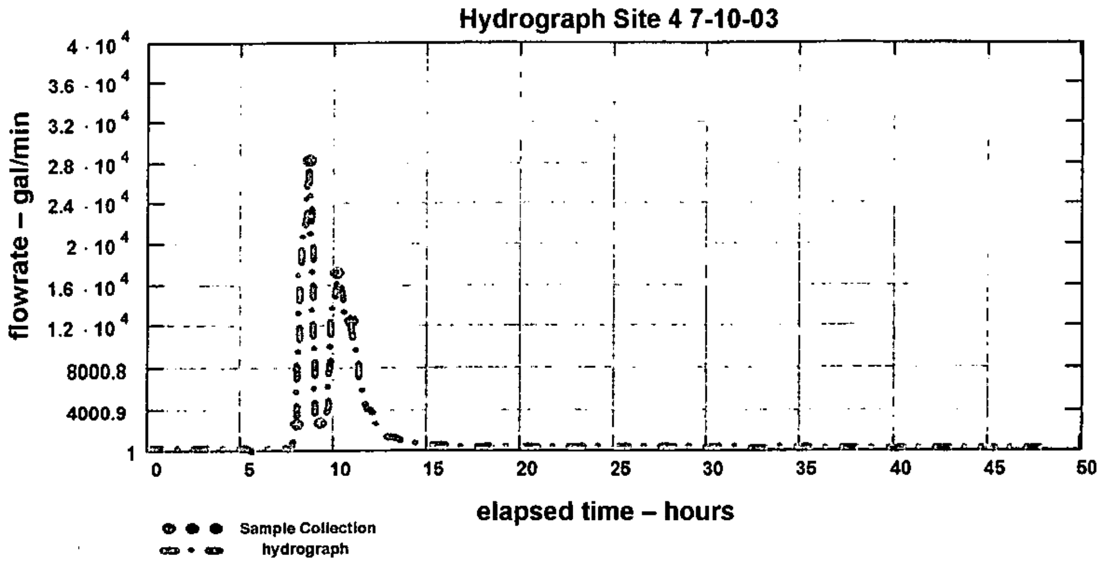

**Site 4 Signal starts at 8:20 am. on 6/26/2003, and ends at 8:20 am on 7/8/2003. Peak at 12:30 pm 6-26-03**

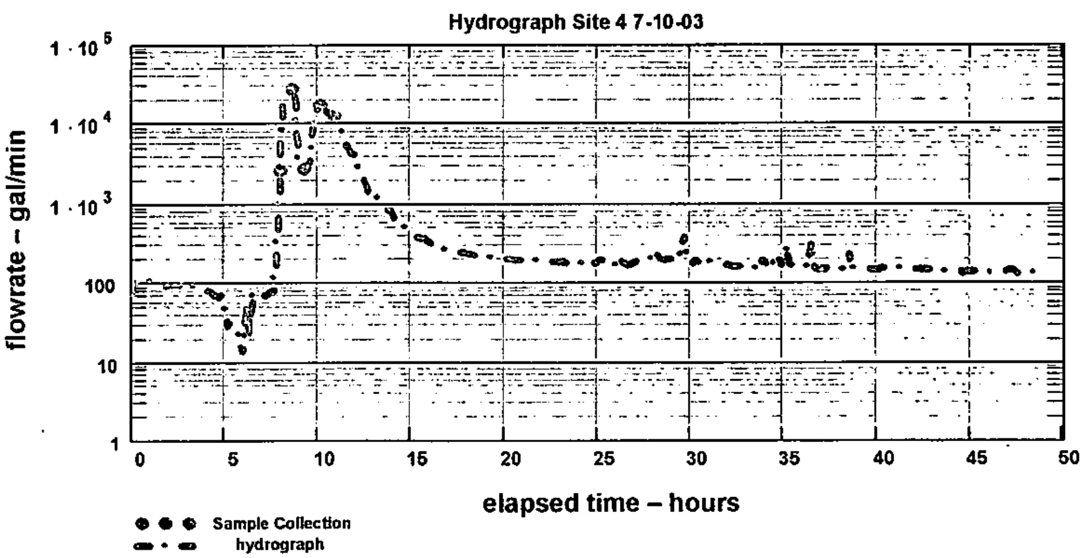
**Figure A-II-11**



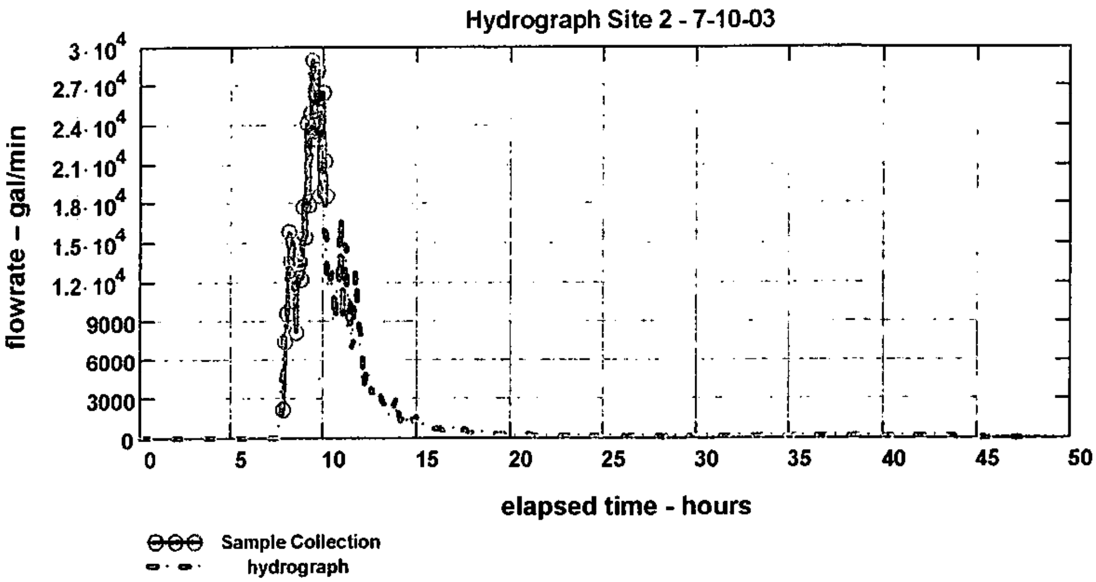

0.91 inches between June 26 and 12:42 pm and June 26 1:48 pm,
1 hour

**Figure A-II-12**
**Site 4**
**7-10-03**



## Figure A-II-12
## Site 2
## 7-10-03



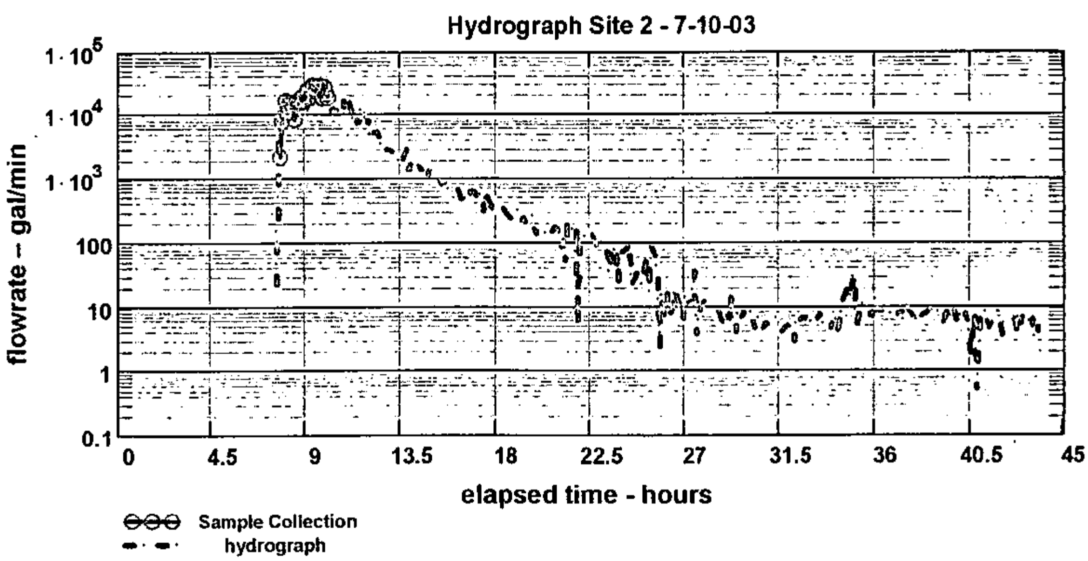
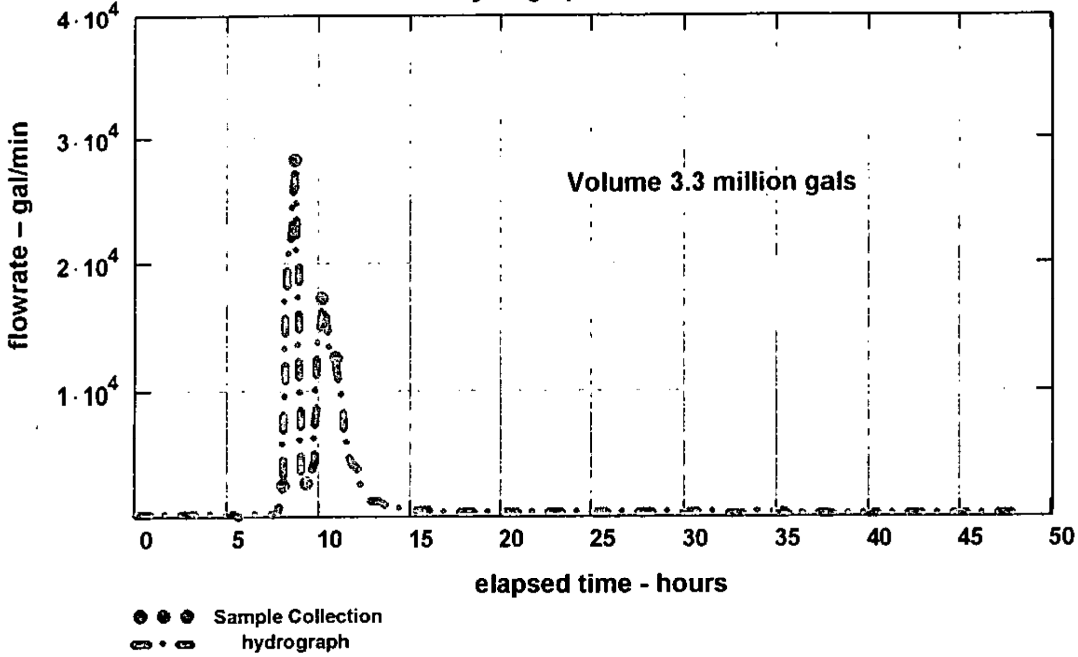



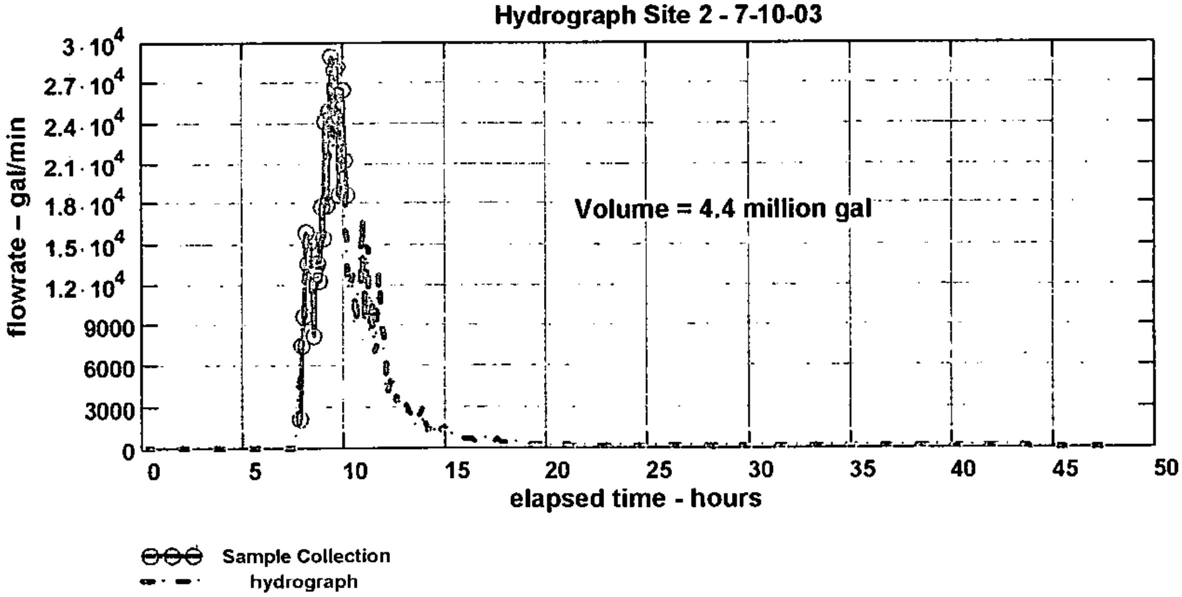
**Figure A-II-12**
**7-10-03**
**Sites 2 and 4**

**Hydrograph Site 4 7-10-03**

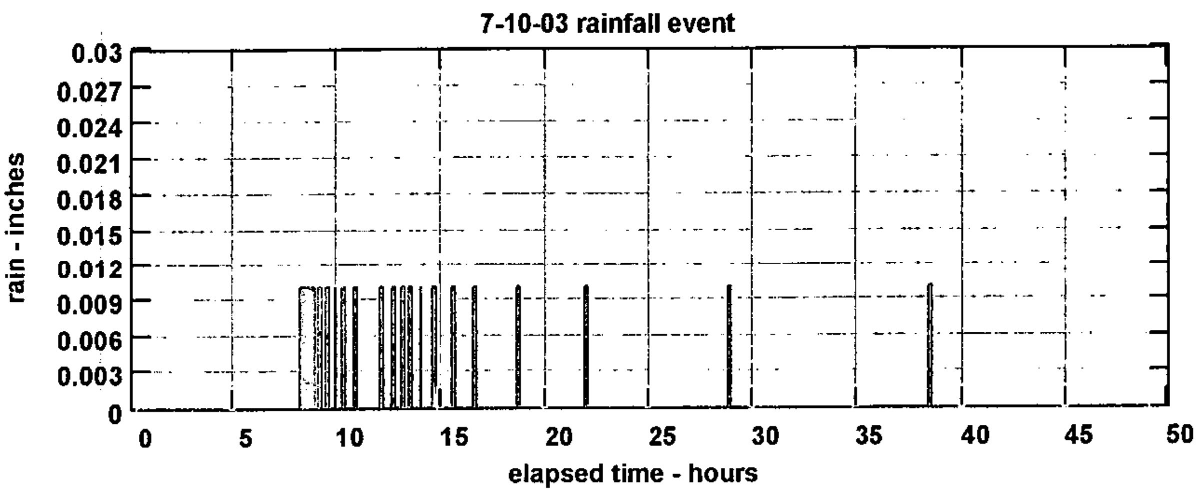



**Site 4 Signal starts at 8:30 am. on 7/8/2003, and ends at 9:00 am on 7/10/2003.**
**Peak at 4:30 pm 7-8-03**

**Hydrograph Site 2 - 7-10-03**




**Site 2 The continous flow starts at 8:54 a.m. on July 8, and ends at 9:30 am on July 10.**
**Peak at 6 pm 7-8-03**




.19 in between July 8 4:30 pm and July 9 3:18 am,
11 hours